THE PLANT DISEASE REPORTER

Issued By

THE PLANT DISEASE SURVEY

Division of Mycology and Disease Survey
BUREAU OF PLANT INDUSTRY, SOILS, AND AGRICULTURAL ENGINEERING
AGRICULTURAL RESEARCH ADMINISTRATION
UNITED STATES DEPARTMENT OF AGRICULTURE

SUPPLEMENT 189

INDEX TO SUPPLEMENTS 180-188, 1949

Supplement 189 Issued May 15, 1950

The Plant Disease Reporter is issued as a service to plant pathologists throughout the United States. It contains reports, summaries, observations, and comments submitted voluntarily by qualified observers. These reports often are in the form of suggestions, queries, and opinions, frequently purely tentative, offered for consideration or discussion rather than as matters of established fact. In accepting and publishing this material the Division of Mycology and Disease Survey serves merely as an informational clearing house. It does not assume responsibility for the subject matter.

P L A N T D I S E A S E R E P O R T E R S U P P L E M E N T

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THE PLANT DISEASE SURVEY
DIVISION OF MYCOLOGY AND DISEASE SURVEY

Plant Industry Station Beltsville, Maryland

INDEX TO PLANT DISEASE REPORTER SUPPLEMENTS 180-188, 1949

Compiled by Nellie W. Nance

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LIST OF SUPPLEMENTS

Supplement 180. Cantaloupe mosaic investigations in the Imperial Valley. pp. 1-15. January 30, 1949. The University of California, the U. S. Department of Agriculture and the Cantaloupe Pest Control Committee of the Imperial Valley cooperating. The results of preliminary investigations by staff members assigned to the project are reported in this Supplement. See its table of contents and author index below.

Supplement 181. Nation-wide results with fungicides in 1948, fourth annual report. pp. 17-87. March 15, 1949. Compiled by the Fungicide Committee of the American Phytopathological Society: Sub-Committee on "Summation of the Performance of Newer Fungicides". See its table of contents and author index below.

Supplement 182. Fungicidal and phytotoxic properties of 506 synthetic organic compounds. pp. 89-109. March 30, 1949. By M. C. Goldsworthy and S. I. Gertler.

Supplement 183. Second annual report of the special committee on the coordination of field tests with new fungicidal sprays and dusts, with reference to the results obtained in 1948. pp. 111-177. April 15, 1949. Foreword and crop fungicide tests by various authors; see its table of contents and author index.

Supplement 184. New or unusual records and outstanding features of plant disease development in the United States in 1948. pp. 179-206. April 30, 1949. Compiled by Nellie W. Nance.

Supplement 185. Preliminary estimates of acreages of crop lands in the United States infested with some organisms causing plant diseases. pp. 207-252. August 1, 1949. Compiled by Paul R. Miller and Nellie W. Nance from reports of collaborators of the Plant Disease Survey.

Supplement 186. Losses from plant diseases: effects on crop industries and on farm life. pp. 253-282. September 15, 1949. Introduction by Jessie I. Wood and Paul R. Miller; contributions from collaborators and from county agents; see author index.

Supplement 187. Cantaloupe mosaic investigations in the Imperial Valley, 1949. pp. 283-296. December 15, 1949. This work is a continuation of that reported in Supplement 180. See its table of contents and author index below.

Supplement 188. The Plant Disease Warning Service in 1949. pp. 297-314. December 15, 1949. By Paul R. Miller and Muriel O'Brien.

Supplement 189. INDEX to Supplements 180-188. pp. 315-336 (Issued May 15, 1950).

AUTHOR INDEX

SUBJECT INDEX

ERRATA

On page 44, the first line under FRUIT ROTS, read Guignardia and Acanthorhyncus instead of Guignardia and Acanthorynchus.

CORRECTIONS FOR SUPPLEMENT 181
(From PDR 33(5):235)

I. Dr. J. W. Heuberger sends in the following corrections to be made in Supplement 181:

1. On page 56 under TENNESSEE under BUCKEYE ROT. The first part of the fifth line now reads "...were no better than the Untreated". Please take the period out after Untreated and add the following: "...except for COCS dust which reduced Buckeye Rot to 13.4% when the Untreated had 19.6%, and which reduced the percentage of total fruit rots to 19.6% when the Untreated had 29.8%. However, COCS dust was applied at a much higher rate (93 pounds of metallic copper being applied per acre) than the other dusts."

2. The following corrections should be made in the list of chemicals according to Dr. S. E. A. McCallan:

"There is no compound 163 containing a mixture of

glyoxalidines, manufactured by Carbide & Carbon, possibly 169, a chromate is what is meant. Compound 531 is a chromate, not a mixture of glyoxalidines. 'Goodrite ZAC, zinc methyl dithiocarbomate Du Pont' is listed. The chemistry and manufacturer are wrong. Listed under ZAC the chemistry is right but manufacturer omitted. This a Goodrich product. Standen 307 is or was also a Goodrich product."

3. In the summary of the vegetable work, make the following changes:

(a) On page 63 under No. 2, insert "in a few tests"between phytotoxic and when so that the first line in No. 2 will read as follows: "The fact that Parzate was phytotoxic in a few tests when.........".
(b) On page 63 for CHROMATE 658 change the last sentence to read as follows: "It was injurious to tomatoes and slightly so to potatoes".

II. Dr. D. E. Ellis adds the following:

The statement in paragraph 1 at the top of page 63 "Anthracnose - North Carolina -" and under "Spergon", page 64 "- and in North Carolina -" apply to Chinese cabbage (Brassica pekinensis Rupr.) rather than to common cabbage (B. oleracea var. capitata L.)

On page 77, paragraph 3 under "Green beans, root-knot, North Carolina -": The materials used were DD, Iscobrome D (instead of Dowfume W-40) and chloropicrin, and each was applied at rates of 200, 400, and 600 pounds per acre (approximately equivalent to 20, 40 and 60 gallons per acre of DD, 27, 54 and 81 g. p. a. of Iscobrome D, and 15, 30 and 45 g. p. a. of chloropicrin).

Trademarks
(From PDR 33(10):404-405)

Ward, Blenkinsop and Co. Ltd., 6 Henrietta Place, London, W. I., send the following communication:

"Our attention has been drawn to the List of fungicides contained in Supplement 181, March 1949, of the Plant Disease Reporter. In this list you include Phenyl Mercury Fixtan as a mixture of Phenyl Mercury Hydroxide and Naphthalene Sulphonic Acid, manufactured by Imperial Chemical Industries Ltd. (PHENYL MERCURY) FIXTAN is our trade mark and manufactured by us. It is not a mixture of Phenyl Mercury Hydroxide and Naphthalene Sulphonic Acid, but the phenyl mercuric salt of 2,2'-dinaphthylmethane - 3,3'-disulfonic acid (Ind. & Eng. Chem. 41, 820, 1949).

"As described in the above reference it is a compound with affinity to fibres. It has not been submitted to any official tests by us, or with our authorisation, in fact the commercial formulation as marketed by us was not completed before March 1949, and it is therefore extremely unlikely that our compound was in fact tested for agricultural purposes by any of your co-operators.

"Because of its highly desirable properties e.g. water solubility and anchoring, the material is at present undergoing various preliminary tests for agricultural purposes, and we shall be pleased to submit any reasonable quantity for trials."

U. S. D. A. - Plant Disease Reporter Supplement number 190 is out of print. Please bind this in its place.

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short 190

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SUPPLEMENT 191

PLANT PATHOLOGICAL INVESTIGATION IN THE UNITED STATES

Supplement 191 May 1, 1950

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PLANT DISEASE REPORTER SUPPLEMENT

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Plant Industry Station · Beltsville, Maryland

PLANT PATHOLOGICAL INVESTIGATION IN THE UNITED STATES

Plant Disease Reporter
Supplement 191 May 1, 1950

FOREWORD

Paul R. Miller

One of the objectives of the Plant Disease Survey is to supply plant pathologists with geographical and historical backgrounds to the problems confronting them. This can only be accomplished with the cooperation of plant pathologists themselves. The series of Supplements to the Plant Disease Reporter, of which this is the first, presenting articles on the broad topic of plant disease investigations in this country, is the result of such cooperation in a project more extensive than most of those suggested by the Survey.

The series was planned to bring out the diversity of plant disease problems in the United States and to show how the results of plant pathological investigation have affected plant disease occurrence and importance, both now and in the past; possibly, furthermore, to indicate the probable effect of present knowledge and action on the types of plant disease situations arising in the future and on methods of handling them. The middle of the century is traditionally a time for review and prediction; moreover, the past several years have seen so much change in problems and attitudes, and such great advance in control, that 1950 may well mark a turning point for historians of plant pathology in time to come.

Pathologists who are taking part in present studies, or who have seen the results of past investigation in their own regions, are best fitted to select and evaluate material for this purpose. Therefore, the Survey asked the help of its State collaborators, who constitute an official part of its organization, and of pathologists in the Bureau of Plant Industry, Soils, and Agricultural Engineering to which the Survey belongs, and in the domestic and foreign plant disease quarantine services in the Bureau of Entomology and Plant Quarantine.

This Supplement contains articles received by April 1. Others will be published later.

The Survey acknowledges its indebtedness to all of these colleagues, who have contributed their time and effort to this admittedly arduous task.

CONTENTS

THE FORWARD MARCH OF RESEARCH ON CEREAL DISEASES

V. F. Tapke and R. W. Leukel

In December 1620 when the Pilgrim Fathers landed at Plymouth, Massachusetts there were some 800,000 Indians occupying the 1,900,000,000 acres of land that now constitute the United States of America. About 2,400 acres of land were available for producing the food of each person. Today our many millions are fed and clothed abundantly with only 14 acres of land per person. Plant pathologists have had a part in making this possible through developing a knowledge of how to save crops from the ravages of disease. What can happen when a disease runs rampant is illustrated by the destruction in a single year of World War I of about 300 million bushels of wheat in the United States and Canada. This loss was due to a pathogenic micro-organism that causes stem rust. Cereals and other crop plants are continually threatened by myriads of disease-producing organisms. Each species of the latter may comprise numerous pathogenic strains and new ones are continually being produced by natural process of mutation and hybridization. Even though only a relatively small percentage of the new ones may be more dangerous than those now in existence, past experience shows clearly the imperative necessity for continued alertness to detect new diseases or new forms of old ones.

The need for never-ending vigilance against new diseases and of coping with established diseases has long been recognized in our country and, better still, combative measures have kept pace with the country's growth. For example, the seed of what is now a huge spreading tree, the Division of Cereal Crops and Diseases, appears to have been sown with the hiring of a plant pathologist in 1894. He was M. A. Carleton, brought into the old Division of Vegetable Pathology and Physiology by B. T. Galloway. Today the Division of Cereal Crops and Diseases employs 17 full time and 2 part time pathologists and carries on cooperative projects with practically every State in the Union, and also in Canada and Mexico. Carleton proved a brilliant worker and set the pattern of things to come. In 1898 he visited Russia and other notable grain-producing countries and brought back varieties of durum and bread wheats and other grains, some of which have been of great value under certain of our conditions. In the severe rust epidemic of 1904, Carleton noted the high degree of resistance of Yaroslav emmer and Iumillo durum wheat. Twelve years later McFadden crossed Yaroslav with Marquis wheat. Out of this cross came Hope and H44, varieties that enter into all modern rust resistant wheats except Thatcher. Iumillo went into the breeding of Thatcher.

In his recent book on Diseases of Field Crops, Dickson describes a total of 130 diseases of barley, corn, flax, millet, oats, rice, rye, sorghum and wheat. Some of these diseases, like cancer in man, are very difficult to cope with. Many take a tremendous toll. The ultimate objective of the field, greenhouse and laboratory studies of cereal diseases is to devise means of eliminating the menace of diseases to cereal crops.

An account of the numerous projects that have made valuable additions to our knowledge of cereal diseases since Carleton's time is not intended herein, but among the outstanding accomplishments the following may be noted:

The discovery of physiologic races of cereal-disease fungi such as the rusts, smuts, mildews, etc. and the use of differential hosts to separate them or distinguish one from another.

The discovery of the relation between scab in wheat and barley and gibberella in corn, and its relation to control measures.

The original study of "take-all" of wheat and the gradual inclusion of studies on foot rots and root rots and later on the virus diseases of cereals.

Studies on diseases at first ascribed to fungi but later found to be physiologic, as: straight head of rice, flax canker, weak neck of sorghum, etc.

Studies on the cause and nature of corn diseases and on methods for their prevention and control.

Histologic studies on the relation of host and pathogen in different cereal diseases.

The writers have chosen arbitrarily two lines of research to illustrate the methods and progress of cereal disease control namely, stem rust of wheat and the control of various diseases through seed treatment. Progress made in this work has been the result of the cooperative efforts between the Division of Cereal Crops and Diseases, U. S. Department of Agriculture and many State Experiment Stations.

SOME ACCOMPLISHMENTS OF RESEARCH ON STEM RUST OF WHEAT

Wheat is the chief food of man at least in the temperate climates of the world. It is grown on some 72 million acres and produces around a billion bushels a year in the United States. Probably no disease has caused greater or more spectacular damage to this great crop than has stem rust. The causal fungus multiplies by means of several kinds of spores. Those that spread the disease from one wheat plant to another are cylindrical in shape and about one thousandth of an inch in length. On a single acre of wheat moderately rusted there about are 10,000 billion of these spores. They can be carried far and wide by the wind. For example, countless billions were blown northward from Texas, Oklahoma and southern Kansas during a period of moderate to strong south winds in 1925. In a week they infected an area of 250,000 square miles.

The breeding of wheat for resistance to stem rust was begun in 1904. The problem is complex because more than 200 pathogenic strains or physiologic races of the parasite exist. A wheat variety may be immune from some races, resistant to others and completely susceptible to still others. Furthermore the prevalence of races varies from year to year and from place to place. The causal fungus moreover also attacks the common barberry producing a sexual stage on this host that may give rise to new races by hybridization between existing races. The eradication of barberries delayed the seasonal onset of early rust in the northern half of the country and also reduced the opportunity for the development of new races. But in southern United States and Mexico, rust exists independently of barberries and then spreads to the north in the spring and early summer months. Consequently resistant varieties are a necessary adjunct in rust control. The United States Department of Agriculture and the Minnesota Agricultural Experiment Station initiated a program of developing wheats resistant to stem rust about 1905. Crosses were made between bread wheats and durum or macaroni wheats since the latter appeared to have some rust resistance. Unfortunately many of the hybrids proved highly susceptible to foot rot and were discarded. More discouraging, a linkage was found between the durum character and resistance to rust. However, through growing large populations of many different hybrid lines, a few plants from a cross between Marquis bread wheat and Iumillo durum wheat eventually were found that possessed the long sought combination of bread wheat characters and durum resistance to rust. The Marquillo variety was developed from one of these plants but it had a number of weaknesses. It was susceptible to root rots, its flour was yellowish, and its rust resistance is not as consistently high as desired.

The Kota variety came into prominence due to its unusual rust resistance for a common spring bread wheat. Kota however was highly susceptible to orange leaf rust, loose smut and stinking smut in addition to having a weak straw. It was crossed with Marquis, and one of the selections from this cross was named Ceres. This wheat had stiffer straw than Kota and was equal to the latter in stem rust resistance. Ceres wheat was distributed in 1926 and rapidly gained in favor. By 1934 more than four million acres of this variety were grown. However, while Ceres was gaining in popularity, a new physiologic race of the rust fungus capable of devastating Ceres came into being. It was race 56 first identified in 1928. It spread rapidly and in 1935 Ceres succumbed heavily to a terrific epidemic of rust due to a combination of factors extremely favorable to the race 56 and certain other stem rust races.

The next rust resistant variety in the march against stem rust was Thatcher, a product of the double cross (Marquis x Iumillo) x (Marquis x Kanred). Thatcher possesses the spring habit and high quality of Marquis, one type of rust resistance from Iumillo and another from Kanred. It is susceptible to the orange leaf rust but it stands up well against the prevalent races of stem rust.

McFadden's production of the Hope and H44 wheats has been noted above. In recent years these two have been used extensively in crosses with the better varieties. Many of the hybrids have shown near immunity from stem rust.

Seedlings of Hope wheat are resistant to many physiologic races of rust, and highly susceptible to others but as the plants grow older they are usually resistant to all races. Hope wheat, therefore, has a type of resistance that gives it great value as a parent in breeding for rust resistance. Adult plants of Hope have rusted heavily at times however under field conditions in Peru and under experimental greenhouse conditions.

Conclusive evidence has been obtained in recent years that new parasitic races of pathogenic fungi may arise through mutation and hybridization. While man is breeding disease resistant crops nature simultaneously is fashioning new strains of the crop pathogens. Obviously, then, continuous research and alertness is essential to keeping abreast with an ever changing situation.

PROGRESS IN CEREAL-DISEASE CONTROL THROUGH SEED TREATMENT

In dealing with a newly discovered plant disease, the plant pathologist's first aim is to discover the identity of the causal organism; his second is to determine its method of spread, and finally he aims to control or to prevent the spread of the disease. While the development of cereal varieties resistant to plant diseases is the ideal method of disease control and the one ultimately sought, it is usually a long-time process. It is highly desirable, meanwhile, to find other methods of prevention, especially for diseases that are spread only by seed-borne pathogens. The proper application of effective fungicides to the seed is the method generally recommended for the prevention of losses due to such diseases.

Some diseases that are seed-borne are also spread by infested soil or crop residues. In such cases seed treatment must be combined with or supplemented by certain cultural practices in order to effect satisfactory control.

Such diseases, as well as those that are entirely soil-borne, are generally combated by crop rotation, sanitation, early or late sowing, or other cultural practices, before and often after resistant varieties have been developed.

The control of diseases that are spread solely by air-borne spores must necessarily be confined largely to the development of resistant varieties, as previously described for the rusts.

The story of cereal seed treatment and its development during the past half-century furnishes an interesting chapter in the history of cereal-disease control, for great advances were made during that period. Seed treatment of wheat with copper-sulfate as a bunt preventive was first suggested by Schulthess as early as 1761 but Kühn in 1866 was the first to evolve a practical formula for its use. The use of hot water for the prevention of all seed-borne cereal smuts was developed by Jensen in 1888, and the use of formaldehyde for controlling some of these smuts was introduced by Bolley in 1896.

Thus, at the start of the century there were but three materials suitable for disinfecting cereal seeds for the control of certain seed-borne diseases, and all three had to be applied with great care to avoid injuring the seed. Copper sulfate was used for the control of bunt in wheat; formaldehyde, in addition to controlling bunt was found to be effective also in controlling the smuts of oats and the covered smut of barley; while the exacting and laborious hot water treatment, although effective in controlling all of these diseases, was used mostly for preventing the deep seated loose smuts of wheat and barley.

In 1920 Mackie and Briggs, following the work of Darnell-Smith in Australia, demonstrated the effectiveness of copper carbonate dust for the control of bunt in the United States, and in a few years this material largely replaced formaldehyde and copper sulfate for this purpose.

In the meantime, certain organic mercury compounds, such as Chlorophol, Germisan and Uspulun, were introduced into this country from Germany. When used as solutions of .2 to .5 percent in which seed was soaked for one-half to one hour, these materials effected excellent control of all seed-borne cereal diseases except the loose smuts of wheat and barley, and without injury to the seed. In fact, germination and stand were frequently improved. But, like the copper sulfate and the formaldehyde soak treatments, they were wet treatments, laborious and disagreeable to apply, and never attained wide popularity. Copper carbonate had pointed the way to a more simple and convenient form of seed treatment for seed wheat and thus had created a demand for a similar form of treatment for other cereal seeds. Chemical companies, therefore, directed their efforts toward the formulation of organic mercury compounds that could be applied in dust form. As a result, research workers, both Federal and State, for a time were deluged with a large number of experimental dusts made by different concerns, many of whom had not even subjected their product to preliminary tests. Many such materials also were imported from Europe, where research on dust seed treatments was advanced somewhat farther than in the United States. Some readers will remember such names as Segetan, Fusariol, Porzol, Abavit, Tutan, Höchst, Tillantin, Agfa, Urania, S.F.A. No. 225, and others. Concerns in this country produced materials with such names as: Wa Wa dust, Mercury C, Bayer Dust, Corona, Seed-O-San, Sterocide, Sanoseed, Acco Dust, Karasch A, Smuttox, Cuprobol, Semesan and Ceresan. Of all these products, only the last two are still sold on the American market.

Some of the materials that were tested were effective in controlling seed-borne diseases of

cereals but were objectionable because of their relative cost, their extremely poisonous nature, their corrosive effect on metal, their narrow margin of safety, their rapid loss of effectiveness, or for other reasons. Many, of course, were rejected because of their fungicidal ineffectiveness. After many experiments with various materials, the following set of requirements for the ideal seed-treatment fungicide in dust form was evolved:

1. It should be effective in disease control.
2. It should not injure seed even when applied at twice the recommended dosage, i.e. it should have a wide "margin of safety."
3. It should be reasonable in price, abundantly available, and easily applied.
4. It should adhere readily to the seed.
5. It should be non-corrosive to metal.
6. It should be stable, and not lose its effectiveness readily.
7. It should not be extremely poisonous or disagreeable to operators.

Needless to say, the ideal fungicide for cereal seed treatment has not yet been developed but a fairly-close approach to it has been made.

The first organic mercury dust fungicide to meet with wide success as a cereal seed treatment in the United States was Ceresan (2 percent ethyl mercury chloride), which was first marketed in 1928. It was effective in the control of all cereal diseases generally amenable to control by chemical seed treatment. However, the recommended rate of application of 2 to 3 ounces per bushel made its high cost -- 9 to 14 cents per bushel of seed treated -- an impediment to its wide-spread use for cereal seed treatment. New Improved Ceresan (5 percent mercury phosphate) appeared on the market in 1933. The recommended rate of application -- 1/2-ounce per bushel -- reduced the cost of material for treating seed to less than 3 cents per bushel. This material largely replaced the original "2%" Ceresan, which has since been used for treating cotton seed, peas, and seeds of certain ornamentals.

In 1948 these two Ceresan products were supplemented by "Ceresan M" (7.7% ethyl mercury sulfonanilide). This material, while fully as effective as its predecessor, New Improved Ceresan, is less disagreeable, less dusty, less vesicant, and less poisonous. Another advantage of Ceresan M is the fact that it can be applied to seed grain as a "slurry", thus eliminating the hazard of flying dust. It is now being widely used for treating seed of cereals and other crops.

The story of corn seed treatment starts in the early twenties with the work of Holbert, Reddy, Erwin, Koehler and others. Some of the early experiments seemed to indicate that no benefit was derived from the practice of corn seed treatment. Later experiments, however, proved that the proper treatment of seed that is infected with Diplodia or Gibberella, or that has injured seed coats, results in better stands and increased yields. This is especially true if cold wet weather follows planting. At first, liquid tretaments such as Chlorophol, Semesan, Corona and Uspulun were used, but these were gradually replaced by dust treatments such as Bayer dust, Corona dust, Merko, Sterocide, Barbak C and Semesan Jr.

These materials gradually disappeared from the market because of relative ineffectiveness, excessive cost or some of the other reasons previously mentioned. They have been replaced largely by the less poisonous non-mercurial organic compounds such as Arasan, Spergon and Phygon.

The wide-spread and ever-increasing use of high-priced hybrid corn seed gave a tremendous impetus to corn seed treatment. The seed companies that produce and sell hybrid seed, in order to guard against poor stands when unfavorable growing conditions follow planting, practically without exception treat their seed before selling it to the growers. Corn seed treatment, to a great extent, has thus been taken out of the farmer's hands. The use of large commercial treaters, effective fungicides, and trained personnel insure efficient treatment of most of the seed corn planted in the United States.

In reviewing the advances in cereal seed treatment during the past thirty years, the period of greatest advances in this field, perhaps the first accomplishment that should be mentioned is the development of relatively safe, effective and inexpensive organic mercury dust treatments, and the elimination of a host of inferior materials by continuous field and laboratory testing. The advent of thoroughly reliable seed treatment materials was followed by vigorous campaigns by extension workers to induce growers to treat their seed. This led to the development of itinerant portable seed-cleaning and treating outfits which move from farm to farm and, for a reasonable price per bushel, treat and clean the seed on the farm. There also were established many central cleaning and treating plants to which the growers haul their seed for cleaning and treating.

During the recent World War the shortage of mercury, which was essential in the manufacture of munitions, led to the production of effective non-mercurial organic fungicides. The extent of their usefulness was determined by extensive laboratory, greenhouse and field tests by State and Federal workers. Spergon and Arasan, for example, were found suitable for corn, rice, sorghum, flax, and wheat, but not for oats and barley. Although the non-mercurial organic materials are less poisonous than the organic mercurials, they have most of the objectionable features that are common to all dust fungicides. This led to the development of the slurry form of treatment, previously mentioned, whereby the dust fungicide is applied to the seed in a soupy water suspension which adds less than one percent of moisture to the seed and leaves the latter coated with the fungicide. This method necessitates the use of a special slurry treater which is too expensive for the average farmer to buy. It generally is used for custom treating at a central plant in connection with a seed-cleaning outfit as previously mentioned. It also is widely used by seed companies who sell treated seed.

The objection to dust treatments because of the discomfort due to flying dust, and the reluctance to use the cumbersome old wet methods of treatment, led also to another form of treatment - the "quick wet treatment." In applying this treatment, a somewhat concentrated solution of a volatile organic mercurial is sprayed onto the seed at the rate of 1 to 2 fluid ounces per bushel, after which the seed is thoroughly mixed, and then stored for at least a day or more to allow the fumes to penetrate to every seed. Special machines have been designed also for applying this type of treatment.

Panogen (2.1% methyl mercury di cyan diamide), a fungicide of this type, is now widely used for cereal seed treatment in some States and to some extent in Canada. So, in contrast to conditions at the time the Division of Cereal Crops and Diseases came into being, when cereal seed treatment was limited to the more or less hazardous use of hot water, copper sulfate, or formaldehyde, applied in a cumbersome, disagreeable manner, we now have a number of materials that are non-injurious to the seed and which can be applied easily and safely either by the grower or by commercial operators.

This great improvement in the cereal seed-treatment situation is the result of close cooperation between commercial chemical concerns and workers in the Division of Cereal Crops and Diseases, along with investigators located at agricultural experiment stations throughout the United States.

PLANT DISEASE RESEARCH ON FORAGE CROPS IN THE BUREAU OF PLANT INDUSTRY, SOILS, AND AGRICULTURAL ENGINEERING

Howard W. Johnson

INTRODUCTION

Research on the diseases of forage crops was conducted by plant pathologists in the Office of Cotton, Truck, and Forage Crop Disease Investigations, and later in the Office of Vegetable and Forage Diseases, for a period of years prior to a reorganization of the plant disease research of the Bureau in 1926. At that time, two pathologists were transferred to the Division of Forage Crops, where their researches have been continued for approximately 24 years. As the research on diseases of forage crops increased in scope, this was recognized in 1928 by a change in name to the Division of Forage Crops and Diseases.

The Division now employs nine plant pathologists for full time work on forage crops diseases. In addition, cooperative agreements are in existence with three State experiment stations, under which the Division pays a portion of the salary of a plant pathologist working on forage diseases while the State pays the remainder of the salary. In still other States, pathologists are under appointment in the Division as collaborators without pay and direct the work of a graduate student employed by the Division on a part-time basis for work on a specific forage disease problem. This increase in the number of plant pathologists working on forage crops diseases during the past twenty-four years is indicative of the increased importance legumes and grasses have assumed in American agriculture during that period.

While the early work on forage diseases in the Bureau centered largely around the diseases of cowpea, alfalfa, and clover, the importance of diseases in the culture of winter legumes was recognized later and work was started on the diseases of winter pea, vetch, and lupine The greatly increased use of grasses, which resulted from the agricultural adjustment and soil conservation programs, emphasized the need for more knowledge of the diseases of hay and pasture grasses. Still more recently, the rapid increase in soybean acreage during the period of World War II, when soybean imports from the Orient were cut off, resulted in an increase in the prevalence of diseases on this crop and led to the initiation of a broad program of research on soybean diseases.

Because of the nature of forage legumes and grasses, direct disease control measures, such as spraying and dusting, have only limited application. Control must be sought in most cases through the development of disease-resistant varieties by selection or hybridization. For this reason, forage crops pathologists have always worked in close cooperation with the legume and grass breeders of the Division and the State agricultural experiment stations.

The research on forage crops conducted by the Division is organized into six main areas, as follows: (1) Alfalfa; (2) Clovers; (3) Soybeans, (4) Lespedeza, Cowpea, and Miscellaneous Legumes; (5) Hay and Pasture Grasses; and (6) Turf. The plant disease research summarized in this paper is organized under these same six headings. More detailed consideration is given the work done on the blind seed disease of perennial ryegrass and on the brown stem rot of soybeans in separate sections of the paper following these six summaries. These two diseases were selected as typical examples of the problems and methods involved in the investigation of forage crops diseases, and both illustrate the achievement of a practical control that is proving of extreme value to farmers.

ALFALFA DISEASE INVESTIGATIONS

A study of the foliage diseases of alfalfa was started in 1916 in cooperation with the Wisconsin Agricultural Experiment Station. Special attention was given to the leafspot caused by the fungus Pseudopeziza medicaginis (Lib.) Sacc. It was found that the fungus lives over winter on dead leaves and that ascospores produced in the spring furnish the source of primary infection. The germinating ascospores were found to penetrate through the cuticle and epidermal cell wall of the leaf with the fungus mycelium developing into a small stroma about the point of entry. An apothecium is produced on the stroma in about two weeks and the ascospores produced in this structure cause secondary infections. No spore form other than the ascospore was found to occur in nature.

During the course of the above studies, it became evident that another disease which had not previously been mentioned as occurring on alfalfa in the United States was responsible, under certain conditions at least, for even greater damage to the crop than the well-known leaf-

spot. This disease was identified as yellow-leafblotch caused by the fungus Pyrenopeziza medicaginis Fckl. The name of this fungus was changed in 1932 to Pseudopeziza jonesii Nannf. It was found that this fungus also overwinters on dead leaves and that infection takes place only from ascospores, which upon germination are able to penetrate the epidermal cells of the leaf. In contrast to the leafspot fungus, the leafblotch parasite produces conidia in abundance in pycnidia that develop in the lesions on living leaves. However, the conidia appear to be incapable of germination and no infections were obtained by conidial inoculations.

Since the only source of infection is the ascospores, it appeared that cutting the alfalfa before these mature on the killed portion of the leaves should greatly reduce the disease. Field observations confirmed this hypothesis, since leafblotch was found to be relatively unimportant in fields cut for hay at the stage usually recommended. It was observed, however, that if infected fields were allowed to remain uncut for an unusually long period, especially in the cool, moist weather of spring and autumn, the disease became abundant and destructive.

Another disease of alfalfa worked on by Bureau pathologists at about this same time is crownwart caused by the fungus Urophlyctis alfalfae (Lagh.) Magn. This disease had been found scattered through several important alfalfa-growing regions in the western part of the United States during the period of 1909 to 1914. A publication dealing with the disease in South America indicated that it might become of considerable economic importance and it was felt that prompt study might reveal the possibility of effective measures against further spread of the disease into other alfalfa-growing regions of the United States.

It was found that infection with Urophlyctis occurs through the very young buds of the alfalfa plant and only in early spring when excessive moisture is present. The galls were found to reach full development early in the summer and to deteriorate rapidly thereafter, only a few surviving until the following spring. No evidence of resistance to the disease was found and it was recommended that growers in the infested region attempt to prevent an excess of moisture in the soil in the early spring, when infection takes place, through drainage or a diminished supply of irrigation water.

The disease has not become more serious in the Western United States, nor has it become troublesome in the central and eastern alfalfa-growing regions, although it has been observed in Clay County, Mississippi, on alfalfa. It appears that the limited distribution of the disease to certain regions of the country is due to climatic conditions which favor the development of the fungus in these localities, rather than to factors which have prevented the spread of the causal organism.

In 1923, the alfalfa eelworm or stem nematode disease was reported as occurring in some of the irrigated valleys of the Western United States. The disease is localized in the crown of the plant and swollen buds and sprouts and enlarged brown stems are characteristic symptoms. The diseased condition is caused by a parasitic nematode or eelworm, Ditylenchus dipsaci, which penetrates the young, tender plant parts and whose presence stimulates the swellings and abnormal development. These organisms may be carried long distances by irrigation water or by hay. In hay, the nematodes show remarkable resistance to drying, since living nematodes have been recovered from hay samples five months after the alfalfa was cut and cured under normal conditions. Spread over shorter distances is accomplished by farm implements.

Alfalfa strain tests in the infested areas have demonstrated in recent years that certain alfalfa introductions from Turkistan are resistant to attack by the stem nematode. Seed of one of these introductions has been increased and released under the variety name "Nemastan" for growth in the nematode-infested areas. Recently, it has been discovered that the stem nematode is present and destructive on alfalfa in at least one area in Virginia. It appears, therefore, that these nematode-resistant alfalfa selections may prove of value in the Eastern United States, as well as in the West where they were made.

A Fusarium wilt of alfalfa, first found in September 1926 near West Point, Mississippi, was described in 1928 and the causal organism was identified as Fusarium oxysporum Schlecht. var. medicaginis Weimer. The leaves of plants affected by this disease turn yellow, the tips of the stems frequently wilt, and the plants eventually die. Frequently, one or more stems of an infected plant wilt and die while the rest of the stems appear healthy for a longer time. The vascular region of diseased plants, especially of the taproot, is usually some shade of brown in contrast to the creamy white color of the roots of healthy plants. Studies of the influence of soil moisture and temperature on infection by this fungus, showed that 55 percent soil moisture was more favorable for infection than was 35 percent and that the optimum temperature for infection was near 25° C.

The yellowing of alfalfa caused by the potato leafhopper, Empoasca fabae (Harris), has been studied over a period of years in cooperation with the entomologists of the Bureau of Entomology

and Plant Quarantine. It was shown that the yellowing, reddening, and dwarfing of alfalfa caused by infestation with this insect was not due to the transmission of a virus but appeared to be due to disruption of the functions of the vascular tissues caused by the leafhopper in its feeding upon the veins of stem tips, petioles, and leaf blades. Similar symptoms were produced by girdling alfalfa stems by means of live steam and it was shown that the chemical changes in leaves reddened and yellowed by artificial girdling and by the feeding of the potato leafhopper are essentially the same.

The work demonstrated that in addition to the marked reduction in yield caused by heavy infestations of this insect, the hay produced is lower in grade, contains less protein, and contains only about one-half the pro-vitamin A present in green alfalfa protected from leafhoppers by dusting or caging.

The most effective control for this insect-induced, disease-like injury would be the development of resistant alfalfa varieties. Work is still in progress on the selection of alfalfa strains resistant to the leafhopper yellowing and it is probable that in the future such resistance will be incorporated in some of the new, disease-resistant varieties that will be produced by the plant breeders working on alfalfa improvement.

Alfalfa dwarf, a disease that occurs only in southern California and whose symptoms and effect on alfalfa stands are quite similar to those of bacterial wilt, was shown in 1936 to be caused by a virus that could be transmitted by grafting. Since then, pathologists and entomologists of the University of California have shown that the virus causing alfalfa dwarf is the same as the virus causing Pierce's disease of the grapevine and that 14 species of leafhoppers can transmit the virus from diseased to healthy plants.

A root rot of alfalfa, found almost simultaneously at Riverside, California, and Madison, Wisconsin, was described in 1938 and the causal fungus was shown to be Stagonospora meliloti (Lasch.) Petr. known previously only as a leaf-spotting fungus of several legumes. The ascigerous stage of the fungus was found to develop on alfalfa stems in the spring and was identified as Leptosphaeria pratensis Sacc. & Briard. The root rot involves the upper part of the taproot and the crown branches. The surface of the lesion is dark brown to black in color while beneath the surface the tissues are reddish brown to almost black. Characteristic wedge-shaped discolorations extend from the bark toward the center of the root. The root rot progresses slowly and is favored by high soil temperatures.

In 1940 a foliage disease of alfalfa and red clover caused by the fungus Stemphylium botryosum Wallr. was reported from Wisconsin. The ascigerous stage of the fungus was found on dead red clover stems and developed in culture on sweetclover stems and potato-dextrose agar. It was identified as Pleospora herbarum (Fr.) Rab. and was shown to be homothallic. The lesions caused by this fungus on alfalfa leaves appear as dark-brown sunken areas that are often surrounded by a straw-colored halo. Concentric zones sometimes develop in old lesions. Conidiophores are produced either singly or grouped in fascicles on such lesions and the conidia are olive brown in color, muriform and have echinulate walls. This organism infects the seeds of several forage legumes.

Rhizoctonia root canker caused by the fungus Rhizoctonia solani Kuehn was shown in 1943 to be a factor in shortening the productive life of alfalfa stands grown under irrigation in southern California and southwestern Arizona. This disease is characterized by dark, slightly sunken areas on the tap root and large lateral roots. The lesions usually occur where young roots have emerged from larger roots. Soil temperatures of 25° to 30° C. were found to favor the development of the disease, while little disease developed at soil temperatures below 20° C. Field observations had revealed previously that the alfalfa plants died out during the summer months, but not during the cooler parts of the year, thus suggesting a close correlation between disease development and warm soil temperature.

In 1940, three species of Colletotrichum were reported as occurring on alfalfa in the Southeastern United States. Two species have straight spores, those of C. trifolii Bain & Essary being mostly 10 to 12 microns long and those of C. destructivum O Gara being mostly 14 to 18 microns long. The third species has spores distinctly curved and about 25 microns long, thus resembling C. graminicolum (Ces.) G. W. Wils. The most commonly reported species is C. trifolii and it appears that this fungus is the cause of much of the anthracnose observed on alfalfa in this region. Lesions are formed on the stems and petioles of the attacked plants and the parts above the lesions wilt, the leaves becoming pale and bleached. More serious damage is caused when infection of the crown and taproot occurs since this results in the wilting and death of entire plants. Anthracnose appears to be a factor in shortening the productive life of alfalfa stands in the Eastern United States and at present is receiving consideration in the alfalfa improvement program in that region.

It was demonstrated in 1925 that the alfalfa wilt disease prevalent in Kansas and Nebraska was caused by a bacterium, Corynebacterium insidiosum (McCul.) Jensen. Since that time bacterial wilt has been found to occur throughout most of the alfalfa-growing areas of the United States and much of the disease work related directly to alfalfa improvement has centered around the testing of varieties and strains for resistance to this important disease. The production of two new bacterial wilt-resistant varieties of alfalfa, Ranger, and Buffalo, through cooperative efforts of the Division and the Nebraska and Kansas Agricultural Experiment Stations, respectively, has eased the strain on this work to some extent in the past few years. As a result, more attention has been devoted to some of the less critical diseases such as leafspot, leaf blotch, stem rot, black stem, anthracnose, rust and downy mildew. Attempts are being made to secure strains of alfalfa resistant to these diseases, so that such resistance can be incorporated into the bacterial wilt-resistant varieties. Since 1934, this program of work has been integrated through the annual meetings of "The Alfalfa Improvement Conference".

CLOVER DISEASE INVESTIGATIONS

Because of its close resemblance to the similar disease of alfalfa caused by Pseudopeziza medicaginis (Lib.) Sacc. the leafspot of red clover caused by the fungus Pseudopeziza trifolii (Biv. Bern.) Fckl. received attention in studies undertaken in 1916 in cooperation with the Wisconsin Agricultural Experiment Station. Efforts to cross these fungi from one host to the other were not successful, however, and it was concluded that the morphological and physiological differences were sufficient to retain the two fungi as distinct species.

This disease is found only on the clover leaves and the spots are dark olive color in the early stages, becoming brown or almost black in later stages. Fruiting disks are not as a rule found on the spots while the leaf is still alive, but they develop abundantly after the death of the leaf. On dead leaves they appear as amber drops of jelly in wet weather, but when dried they become small and inconspicuous. The fungus was found to overwinter on dead clover leaves and the ascospores produced in the spring furnish the source of new infection. As in the case of the similar parasite of alfalfa, the ascospore appears to be the only spore form that occurs.

An investigation of diseases as a factor in "clover failure" led to a study of the two principal anthracnose-producing fungi of red clover, Colletotrichum trifolii Bain & Essary and Kabatiella caulivora (Kirchn.) Karak. The results of this study were published in 1928 and showed that while the macroscopic symptoms produced by these two fungi on red clover were nearly identical, differences existed in spore characters, setae, and host range. It was concluded that these differences fully justified separation of these fungi as distinct species.

In fields severely affected with anthracnose, the most conspicuous symptom is that of drooping leaflets and flower heads. The drooping parts soon wilt and turn brown, and as more serious infection kills whole stems or entire plants, the field becomes spotted with brown areas. In severe cases fields appear as if injured by fire, which has led to the name "scorch" being used in some localities to designate anthracnose. In addition to the lesions on the petioles, flower stalks and stem, these fungi cause a spotting of the leaves and may infect and rot the crown and upper portion of the taproot.

The anthracnose caused by C. trifolii occurs most injuriously in the southern half of the clover belt of the United States, while that caused by K. caulivora is more common in the northern half. Infection experiments conducted at constant air temperatures showed that the optimum for the development of anthracnose caused by C. trifolii is about 28° C. This temperature response is cited as the cause of the southern distribution of this disease.

Control by means of resistant varieties was suggested as offering the most promise and attention was called to the fact that red clover seed from stock produced in regions where the disease is regularly severe is in general much more resistant to anthracnose than are strains of red clover from other regions. Because of the characteristics of the anthracnose disease, the process of natural selection plays an important part in increasing the degree of resistance in red clover grown continuously in an anthracnose-infested region.

Cooperative efforts of the Division and several of the State agricultural experiment stations along the lines suggested above have resulted in the production of two new varieties of red clover that are now widely grown. Cumberland, which is adapted to the southern part of the red clover growing area, possesses considerable resistance to Colletotrichum anthracnose since it originated from selected strains of red clover grown for many years in Tennessee, Kentucky, and Virginia, where they have been exposed regularly to severe natural outbreaks of this disease.

Similarly, the variety Midland was developed from old Corn Belt strains of red clover and

is adapted to the northern part of the red clover belt where it demonstrates some resistance to Kabatiella anthracnose, as a result of the natural selection that had occurred in these old strains.

More recently, the red clover variety Kenland has been released through cooperative efforts of the Kentucky Agricultural Experiment Station and the Division. The strains making up this variety were first exposed to artificially induced epidemics of Colletotrichum anthracnose and later to stem rot and other clover diseases over a period of several seed generations, with seed harvested from the surviving plants. This variety, therefore, has a somewhat broader base of disease resistance than any previously released red clover; and, consequently, many of the plants persist into the third or fourth years of growth.

Studies of the powdery mildew disease of red clover caused by the fungus Erysiphe polygoni DC. were undertaken in cooperation with the Purdue University Agricultural Experiment Station and were continued in cooperation with the Wisconsin Agricultural Experiment Station. In a report of this work published in 1936, three physiologic forms of red clover powdery mildew were distinguished by differences in the reaction of certain red clover clones. It appeared from the limited tests made with mildew collections from various locations that form 1 is widely prevalent, whereas, forms 2 and 3 are relatively rare.

It was shown also that the red clover powdery mildew fungus manifests a definite diurnal cycle, certain phases of fungus activity occurring regularly at a certain time of the day. For example, practically all of the conidia formed during the 24 hours of the day were found to mature between 8:00 a.m. and noon. It was concluded that the alternating light and dark of the normal day are responsible for the cyclic manifestations of the fungus.

The selection of powdery mildew-resistant red clover plants followed by controlled crossing between these resistant selections and brother-sister mating within the lines thus established has been carried on over a period of approximately 15 years in cooperative work of the Division and the Wisconsin Agricultural Experiment Station. Several of the powdery mildew-resistant red clover lines developed in this way have been used in making synthetics. Seed of one such synthetic has been increased and is now being tested widely prior to release as a powdery mildew-resistant variety of red clover.

A leafspot disease of red clover caused by the fungus Stemphylium botryosum Wallr. was reported from Wisconsin in 1940. The ascigerous stage of the fungus was found on dead red clover stems and was identified as Pleospora herbarum (Fr.) Rab. The leaf lesions caused by this fungus on red clover are irregular in shape and dark brown to black in color. A straw-colored halo often develops around each lesion. Small black linear lesions are produced on stems and petioles, but the fungus appears to cause most damage as a leafspot. The conidia formed by this fungus are echinulate which serves to differentiate it from a closely related fungus, S. sarcinaeforme (Cav.) Wiltshire, with smooth-walled conidia that causes a similar leafspot on red clover.

Clover rust, caused by the fungus Uromyces trifolii (Hedw. f.) Lév., attacks all of the common clovers and is sometimes severe enough on white, alsike, and red clovers to cause loss of leaves and thus reduce the yield obtained. In 1941, workers at the U. S. Regional Pasture Research Laboratory reported that rusted leaves of white clover contain from one-fifth to one-third less carotene (pro-vitamin A) than do non-rusted leaves. It would appear, therefore, that the nutritive value, as well as the yield, of the clover crop is reduced by clover rust.

Stem rot of clovers, caused the fungus Sclerotinia trifoliorum Erikss., has been recognized in this country since 1890. It appears to be most prevalent in western Oregon and in the eastern part of the red clover-growing area. The fungus is most active in late winter and early spring when it rots the stem bases and upper taproot of the attacked plants. Serious outbreaks have been reported on crimson clover, red clover, white clover and sweetclover. Work reported in 1949 from the U. S. Regional Pasture Research Laboratory shows that this fungus is responsible for an extensive killing of Ladino clover stolons that becomes evident in the spring. It appears, therefore, that stem rot may be a major factor in the winter survival of this large-growing strain of white clover which has recently become one of the major pasture legumes in the United States.

A virus disease of Ladino clover characterized by stunted plants and chlorotic, yellow mottling of the leaves was described in 1949 as a result of cooperative studies conducted by the U. S. Regional Pasture Research Laboratory and the University of Pittsburgh. The disease was given the common name of "yellow patch" and the causal virus was identified from host range and other properties as a strain of alfalfa mosaic virus different from any previously described.

A blighting of sweet clover stems described in Germany in 1903 was first recorded in the United States in 1938 and the causal fungus was identified as Ascochyta caulicola Laub.

This fungus causes bleached areas, sometimes accentuated by a brown border, which are soon dotted with black pycnidia. In vigorously growing plants, it causes a characteristic bending of the stems and the common name "gooseneck" has been suggested for the disease. The fungus was isolated from the seed of diseased plants and appeared to be systemic to some degree.

Further studies published in 1939 showed that three other fungus parasites of sweetclover also infected the seed, i.e. Cercospora zebrina Pass., Leptosphaeria pratensis Sacc. & Briard, and Mycosphaerella lethalis Stone. No external evidences of the presence of these fungi in the seed were discovered. None of the fungi immediately attacked or damaged the seedlings bearing them and the extent to which this seed infection leads to the incidence of important diseases of sweetclover in agriculture remains to be determined.

A root rot of sweet clover that had been observed in the Corn Belt States since 1930 was described in 1939 and the causal fungus was considered to be Phytophthora megasperma Drechs. However, the same disease was found by a Canadian pathologist in Alberta in 1940, and the true parasite was identified as a strain of P. cactorum (Leb. & Cohn) Schroet. The existence of the root rot is first evident in the spring by the wilting and death of individual plants. When the roots of such plants are dug, a portion is found decayed. The disease is most abundant in low, wet portions of fields, where during seasons of heavy spring rainfall, it may destroy almost all of the plants quite rapidly.

Root rot-resistant sweetclover plants were obtained by inoculating fall-dug roots with the fungus in the greenhouse during the winter months. Selfed seed was obtained when these plants matured the following spring. Thirteen of these progenies were inoculated and gave 50 to 75 percent of healthy plants in comparison with 10 percent healthy plants from the progeny of an unselected sister plant. It appears, therefore, that resistance to Phytophthora root rot can be increased greatly by selection.

SOYBEAN DISEASE INVESTIGATIONS

Intensified soybean disease research in the past few years has revealed the existence of three diseases previously not known to occur on soybeans in the United States. These diseases are: (1) bud blight, a virus disease; (2) wildfire, a bacterial disease; and (3) brown stem rot, a fungous disease. Of these three diseases, brown stem rot perhaps causes the greatest losses, being particularly severe in Illinois where it was first discovered, but now becoming increasingly important in Indiana, Iowa, Missouri, and Ohio. This disease is discussed more fully in a later section of this paper. Wildfire, on the other hand, appears to be more prevalent and destructive on soybeans in the Southern States. Bud blight has been observed rather generally over the Corn Belt States, but severe outbreaks have occurred in only a few localized areas. It is rarely seen on soybeans in the South.

Major efforts in the soybean disease program have been directed toward determining the resistance of varieties and strains of soybeans to the three bacterial foliage diseases; i.e., blight, pustule, and wildfire. Disease readings have been made on the varieties and strains planted in uniform soybean nurseries at various locations in the twenty-four States cooperating with the U. S. Regional Soybean Laboratory. These field observations have been supplemented by artificial inoculation tests conducted in the greenhouse and in field plots. As a result of these studies, it has become apparent that none of the Corn Belt varieties of soybeans have a high degree of resistance to the bacterial foliage diseases, other than some varietal resistance to bacterial blight. On the other hand, two of the southern varieties, CNS and Ogden, have proved highly resistant to bacterial pustule and remain relatively free from wildfire. While blight attacks these varieties during the early part of the growing season, foliage injury is usually not extensive. Consequently, these two varieties have been used in numerous crosses in an attempt to obtain superior disease-resistant varieties of different maturities for the South.

Studies are underway on the method of over-wintering of these three bacterial parasites of soybeans; on the inter-relations of the three in mixed cultures and when inoculated on soybean plants; and on the effect of different environmental factors such as temperature, age of leaf, dilution of inoculum, variety of host, etc., on symptomatology.

Investigations of the pod and stem blight disease made in cooperation with the Iowa Agricultural Experiment Station have shown that two members of the genus Diaporthe occur on soybeans and that these differ in pathogenicity and type of perithecial development. A heterothallic form, identified as D. phaseolorum (Cke.) Ell. var. sojae (Lehm.) Wehm. has scattered, single perithecia and produces typical Phomopsis conidia. It is the less pathogenic of the two, attacking mainly mature plants and producing linear rows of pycnidia on branches and stems. A homothallic form, identified as D. phaseolorum (Cke.) Ell. var. batatatis (Harter & Field) Wehm.

produces caespitose clusters of perithecia and lacks conidial stages. It is an active parasite on soybeans, attacking and girdling the stems, and causing the plants to wilt and die.

Studies of the charcoal rot disease, made in cooperation with the Missouri Agricultural Experiment Station, have shown that isolates of the causal fungus, Macrophomina phaseoli (Maubl.) Ashby, vary considerably in their pathogenicity on soybeans. None, however, possess a high degree of pathogenicity on this host and infection appears to be limited to young seedlings, senescent plants, and plants growing under extremely unfavorable environmental conditions. The disease was found in commercial plantings only in a season of severe drought and high temperatures. The disease occurred most commonly on very sandy soils, in drill-seeded fields, in weedy fields, and at the border of fields. Low soil moisture levels were a major factor contributing to the development of the disease in both commercial plantings and greenhouse inoculation tests.

Downy mildew, caused by the fungus Peronospora manshurica (Naoum.) Syd., was considered to be strictly a foliage disease of soybeans in this country until 1942 when it was shown that the oospores of this fungus encrust the soybean seed, giving them a milky appearance. This condition has since been observed on soybean seed from numerous localities, and is apparently of rather common occurrence in all soybean growing areas of the United States. Studies have shown that when such seed are planted in the greenhouse, they give rise in some cases to downy mildew-infected seedlings with the lesions connected by mycelium in a systemic infection. Young plants with such systemic infection have been collected in the field and the characteristic mycelium of the downy mildew fungus has been found in all parts of the young plants through the hypocotyl and first trifoliate leaf.

Soybean seed treatment tests have been conducted in cooperation with the State agricultural experiment stations in the North Central, Southern, and Eastern States since 1943. These tests have shown that in many localities significant increases in stand result from treating soybean seed with a fungicide before planting. Arasan and Spergon have, in general, given somewhat better results than the other fungicides included in the tests. The most pronounced improvements in stand have been obtained with seed lots of rather low germinability and it appears that when weather conditions at harvest time in the fall are such as to cause damage to the soybean seed, seed treatment the following year may be advisable. In the Southern States, varieties that mature in September usually produce seed of lower viability than do those of October maturity. Treating the seed of these earlier varieties in this region may mean the difference between a satisfactory stand and a poor one in many years.

Dusting experiments have been conducted in cooperation with the North Carolina Agricultural Experiment Station since 1945 to determine the effectiveness of copper dust in controlling the leaf and stem diseases of soybeans, particularly the three bacterial foliage diseases. In some seasons, dusting has resulted in rather effective control and a significant increase in yield of seed. In other years, dusting has appeared to be rather ineffective. The variant results have been due apparently to seasonal weather conditions, timeliness of dust applications and various other factors.

In 1948, a severe infestation of purple seed stain, caused by the fungus Cercospora kikuchii Matsu and Tomoyasu, developed on soybeans in North Carolina. Counts of the purple-stained seeds on the harvest from the dusting test showed a reduction of 40 to 50 percent in purple-stained seeds as a result of dusting the soybean plants with tribasic copper sulphate. Further work on the dusting of soybeans to control diseases appears warranted, since in some areas of the South airplane dusting with the new organic insecticides is becoming a rather common practice to control such insect pests of soybeans as the bean leaf beetle, the cotton boll worm, and the velvet bean caterpillar.

LESPEDEZA, COWPEA, AND MISCELLANEOUS LEGUME DISEASE INVESTIGATIONS

A wilt disease of annual lespedeza first observed at Arlington, Virginia, in the summer of 1937 was shown to be caused by a previously undescribed bacterium, Xanthomonas lespedezae (Ayers et al.) Burkh. The disease is now known to be widely distributed in the lespedeza-growing areas of the United States, but appears to be most severe on strains of Early Korean lespedeza in Illinois, Iowa, and Missouri. It has been shown that the wilt bacterium may occur either in or on the seed of annual lespedeza and it seems probable that this is the method by which the organism has been carried from region to region.

Powdery mildew of annual lespedeza is caused by the fungus Microsphaera diffusa Cooke & Peck. While this disease usually develops too late in the season to cause serious losses, it does

appear to cause a certain degree of premature defoliation. Strains of Common and Kobe lespedeza appear to be somewhat more susceptible to this disease than do strains of Korean, at least in certain regions.

An anthracnose of annual lespedeza caused by a strain of Glomerella cingulata (Stonem.) Spauld. & Schrenk was described for the first time in 1946. This disease is known to occur in Georgia, North and South Carolina, and Virginia. The disease is most conspicuous as a leafspot but lesions are produced also on the petioles and stems. Seedlings may be stunted or killed during the spring and early summer months and considerable defoliation may be caused but stands are never seriously depleted. Strains of Kobe and Common lespedeza (L. striata) are more susceptible to anthracnose than are strains of Korean (L. stipulacea.)

Some of the earliest work on cowpea diseases in the United States involved the testing of cowpea varieties for resistance to Fusarium wilt and root-knot on "pea-sick" soil near Monetta, South Carolina. As a result of these tests, the Iron variety of cowpea, which had been found in cultivation in Barnwell and Aiken Counties, South Carolina, was shown to be highly resistant and seed of this variety was distributed to growers in the Southern States. Later, Brabham and Victor, hybrid varieties of cowpea with Iron in their parentage, were likewise found to be resistant to wilt and root-knot.

One of the most serious and widespread diseases of cowpea observed in recent years is bacterial canker, caused by Xanthomonas vignicola Burkh. It is interesting to note that Iron, Brabham, and Victor are among the varieties resistant to this disease and that these varieties are now being used in crosses to produce new, superior varieties of cowpea resistant to wilt, root-knot, and bacterial canker.

In some localities in the South, diseases became so destructive on Austrian winter peas about 1930 that the growing of this otherwise desirable winter cover crop was practically abandoned. To help meet this situation, the Division placed a plant pathologist at Experiment, Georgia. His surveys revealed that the most destructive diseases are: (1) leafspot and black stem caused by Ascochyta pinodella L. K. Jones and Mycosphaerella pinodes (Berk. & Blox.) Stone; (2) leaf blotch caused by Septoria pisi West.; (3) root rot caused by Aphanomyces euteiches Drechs.; and (4) powdery mildew caused by Erysiphe polygoni D.C.

Since a number of these fungi live over from one crop season to the next in the soil or in pieces of diseased stems, he recognized that the prevalence of the fungi in the soil would increase from year to year if peas were planted on the same fields each autumn. Observations in growers' fields and in rotation plots at the Georgia Agricultural Experiment Station led to the conclusion that if winter peas are planted on the same land not oftener than one year out of three or four, losses due to diseases will be greatly reduced. This recommendation was made to the growers.

Studies of varietal resistance to the diseases yielded little encouragement, so a program of hybridization was undertaken in an attempt to produce new, agronomically desirable, disease-resistant strains of winter peas. This work resulted in the production of three strains with considerable resistance to Aphanomyces root rot. Seed of one of these strains is being increased in Oregon and should soon be available to growers in the South. No resistance to leafspot and black stem was observed in these hybrids, but these diseases are rather effectively controlled by rotation as recommended above.

A leafspot of Augusta vetch was shown to be caused by the fungus Botrytis cinerea Fr. in 1944. Inoculation experiments showed that smooth and purple vetches were highly resistant to the disease, while Vicia sativa (all strains that were tested), V. grandiflora, and V. faba were susceptible in addition to V. angustifolia.

An anthracnose disease of vetches was described in 1945 and the causal organism was described as Colletotrichum villosum Weimer. This fungus causes both leaf and stem lesions that are quite similar in appearance to the lesions of the more common false anthracnose disease caused by Kabatiella nigricans (Atk. & Edg.) Karak. Inoculation tests showed that Vicia atropurpurea, V. villosa, and V. dasycarpa are the most susceptible species while V. sativa, V. grandiflora, V. monanthos, V. angustifolia, and V. pannonica are fairly resistant.

A greatly increased acreage of kudzu (Pueraria thunbergiana) has been planted in the Southeastern United States during the past 15 years as a result of the soil conservation program. These plantings have remained relatively free from diseases, except for a rather general infestation with bacterial halo spot caused by Pseudomonas phaseolicola (Burkh.) Dows. However, in 1947, a fungus leafspot was found on kudzu in several counties in Central and South Georgia. It appeared to be causing the premature shedding of many leaves and varying degrees of injury to others. The causal fungus was identified as Cercospora pueraricola Yamamoto. Cooperative investigations of a Division pathologist and one employed by the Georgia Agricultur-

al Experiment Station resulted in the discovery of the perithecial stage of the causal fungus on overwintered kudzu leaves and it was described in a 1948 publication as Mycosphaerella pueraricola (Yamamoto) Weimer & Luttrell. The common name "angular leafspot" was suggested for the disease and it was pointed out that this disease of kudzu had been reported from Formosa in 1934 and from China in 1936. It seems probable, therefore, that this fungus was introduced into the United States on kudzu seed imported from the Orient.

During recent years, three species of imported lupines, Lupinus angustifolius (blue lupine), L. luteus (yellow lupine), and L. albus (white lupine), have been grown experimentally in the Southeastern United States and the blue lupine has become established as a winter cover crop in the Coastal Plain sections of Georgia, Alabama, and northern Florida. As the cultivation of this crop increased, it became evident that it was susceptible to attack by a number of diseases.

In March 1943, an anthracnose of lupines not previously reported in the United States was described and the causal fungus was identified as Glomerella cingulata (Stonem.) Spauld. & Schrenk. Inoculation experiments showed that under conditions of high humidity this fungus attacks young plants of both blue and white lupine. Yellow lupine was not infected in the single test made with this species.

In April 1943, a cankering of the stem and branches of blue lupine was shown to be due to attack by the fungus Botrytis cinerea Fr. It was found that while frozen tissue is not essential for infection, it forms an excellent infection court for this fungus and that damage caused by late spring freezes may be considerably augmented by the fungus.

In 1944 some root rots and a foot rot of the three species of lupines were described. The root rots were shown to be caused by several species of Fusarium, by Rhizoctonia solani Kuehn, and by Pythium graminicolum Subr. The foot rot was shown to be caused by the common southern blight fungus, Sclerotium rolfsii Sacc. The pathogen most frequently isolated was Fusarium oxysporum Schlecht. f. radicis-lupini Weimer and it was concluded that this fungus is the most common cause of the root rotting of lupines found in the southeastern part of the United States. The selection of resistant strains of the hosts appears to be the most hopeful control measure for these diseases.

In December 1947, the leafspot disease of lupines caused by the fungus Ceratophorum setosum Kirchn. was found for the first time in the United States in a field of blue lupine near Perry, Georgia. An extensive survey of the major lupine-growing sections of the Southeastern United States made in March 1948, revealed that this disease, known by the common name "brown-spot", was present in all the localities visited in Georgia, Florida, and Alabama, and that in many places it was causing considerable defoliation from the base of the plants toward the top. In addition to the leafspot symptoms, it was observed that the fungus caused lesions on the petioles and stems. In some cases the stem lesions were in the form of large cankers resembling those produced by anthracnose.

Lesions similar in appearance to those observed on blue lupines were found on yellow and white lupines at two locations in Florida, thus showing that all three species of lupines are susceptible to attack by this fungus. Heavy rainfall and continued cloudiness throughout much of the Southeastern United States from November 1947 to March 1948 appeared to have retarded the growth of the lupines and to have been factors in accentuating the amount of damage from this disease.

Seed production of winter cover crop legumes in the Southeastern United States has been rather uncertain and much of the seed planted each fall has been purchased from seed producers in the Pacific Northwest. The blue lupine has been an exception to this general rule and yields of 1, 000 to 1, 500 pounds of seed per acre are quite common. The abundant seed crop it produces in the Southeast has been an important factor in the rapid increase in the acreage planted to blue lupine. The storing of this large seed crop from harvest in May until planting time in the fall has presented serious problems in this humid area and recently a project has been set up that is attempting to solve some of these problems. Since microbiological factors are among those involved in the storage of blue lupine seed, pathologists are participating in this project.

HAY AND PASTURE GRASS DISEASE INVESTIGATIONS

Some of the earlier work on grass diseases in the Bureau involved studies of the susceptibility of wild grasses to attack by certain cereal rust fungi and a rather extensive study of the graminicolous species of Helminthosporium. The initiation of an expanded program of grass breeding investigations by the Division in 1935, and the establishment of extensive grass nur-

series by the Soil Conservation Service at about the same time, provided a mechanism for evaluating grasses as species, varieties and strains under a wide variety of environmental conditions. Differences between varieties and strains in the breeding and soil conservation nurseries, including differences in susceptibility and resistance to diseases, soon became apparent and it was recognized that the investigation of grass diseases coincident with the breeding procedure was an essential phase of grass improvement. Recognition of this fact resulted in the setting up of an expanded program of grass disease investigations at that time.

The wide variety of grass species involved and the still wider range of parasites made it essential that considerable time be spent at first in survey work to determine the relative prevalence and economic importance of the various types of grass diseases. Hundreds of grass disease specimens were collected and examined and several extensive indices to the diseases observed on the various grass species were published in The Plant Disease Reporter.

When this data had been assembled, certain generalizations became evident. The paucity of smuts and stem rust on grasses in the Southeastern United States is very noticeable as compared with what is found in the more Central States and the Far West. Root rots also do not appear to cause the injury to grasses in the Southeastern States that they do in some of the more western sections of the country. On the other hand, ergots of grasses are widely distributed and rather common. Leafspots likewise are rather generally distributed but are usually much more prevalent in those regions where the climate is more humid.

Studies of the smut diseases of grasses have been conducted in the Pacific Northwest over a period of years in cooperation with the Soil Conservation Service and the Washington Agricultural Experiment Station. These studies have resulted in publications on the life history and physiologic specialization of four grass smuts of definite economic importance in this region, i.e., (1) stripe smut caused by Ustilago striiformis (West.) Niessl; (2) head smut caused by Ustilago bullata Berk.; (3) stem smut caused by Ustilago spegazzinii Hirsch.; and (4) flag smut caused by Urocystis agropyri (Preuss) Schroet. Other grass smuts of more mycological than pathological interest have also been studied.

Tests of the susceptibility of strains of various economic grasses to the more important grass smuts have been conducted by means of artificial inoculations and considerable strain differences in smut reaction have been noted. For example, certain accessions of blue wild rye, Canada wild rye, slender wheatgrass, and mountain bromegrass submitted for testing by the Soil Conservation Service were found to be immune to certain of the smut diseases while other accessions were quite susceptible. Such information has been of value in determining what grass strains should go into seed production in the conservation nurseries, as well as in providing the grass breeders with smut-resistant or immune grass strains for use in hybridization.

Seed treatment tests for the control of head smut of grasses and for the improvement of stands by control of seedling diseases were conducted also as a part of this cooperative work. Of the materials tested, 2 percent Ceresan and New Improved Ceresan proved best, giving excellent smut control and from 300 to 500 percent better stands than the non-treated check plantings. On the basis of these results, either 2 percent Ceresan at 2 to 4 ounces per bushel weight of seed or New Improved Ceresan at 1/2 to 1 ounce per bushel were recommended for combined control of head smut and stand improvement.

A study of the prevalence and distribution of stripe smut in Kentucky bluegrass (Poa pratensis) pastures in Pennsylvania was made by workers at the U. S. Regional Pasture Research Laboratory. Sod plugs from each of 13 representative pastures were collected and observed periodically over a period of five months. The total number of plugs found to contain smutted plants varied for different pastures from 4.5 to 34.4 percent. The high percentage of smutted plugs collected from some of the bluegrass pastures leaves little doubt that stripe smut is important in reducing their productivity.

In further studies of the stripe smut of Kentucky bluegrass made at this laboratory, smutted plants were grown at different, controlled air temperatures. This experiment showed that both host and parasite grew well for five months at temperatures of 1.5°, 10°, and 20° to 25° C. At 32° C., on the other hand, only 14 out of 23 smutted plants were alive after four months, and 9 of these 14 plants showed no visible evidence of smut infection. When these plants were placed at a lower temperature and were permitted to grow for a time, smut symptoms appeared again in most cases. Chlamydospores removed from leaves of the smutted plants growing at 32° C. proved to be highly germinable without any after-ripening period, whereas, those from plants growing at 1.5°, 10°, and 20° to 25° C. failed to germinate unless after-ripened.

As part of the grass disease investigations conducted in the Pacific Northwest in cooperation with the Soil Conservation Service and the Washington Agricultural Experiment Station,

studies were made also of stem rust of grasses caused by the fungus Puccinia graminis Pers. An epidemic of stem rust developed on many grasses in the Pullman, Washington, area during the summer and fall of 1940 and collections were made on big bluegrass (Poa ampla), on wild oats (Avena fatua), and on blue bunch wheatgrass (Agropyron spicatum). One hundred and twenty-three species of grasses and cereals, in 23 genera, were used in host-range studies with these three collections of stem rust. The Poa rust culture infected 34 species representing 14 genera of grasses, the Avena rust culture infected 18 species in 9 genera, while the Agropyron rust culture infected only 7 species representing 3 genera of grasses.

The culture of stem rust from Poa ampla was identified as a new physiologic race of Puccinia graminis avenae Erikss. & E. Henn. occurring primarily on grasses. The culture from Avena fatua was identified as physiologic race 2 of P. graminis avenae. The culture from Agropyron spicatum did not seem to belong to any known variety of P. graminis and was thought to be a new variety of stem rust that is highly specialized to Elymus glaucus and a few species of Agropyron and Sitanion.

Studies of the reaction of collections of meadow fescue, Festuca elatior, and of tall fescue, F. elatior var. arundinacea, to crown rust, Puccinia cornata Cda. by workers at the U. S. Regional Pasture Research Laboratory were reported in 1947. They found that most collections of meadow fescue (14 chromosomes) are susceptible while those of tall fescue (42 chromosomes) are usually resistant. However, one collection of meadow fescue obtained from Maine was immune to this rust. The discovery of rust-immune material in the 14-chromosome condition should simplify the transferring of rust resistance to strains of F. elatior that are agronomically desirable but susceptible to P. coronata.

A series of drought years and the resultant dust storms in the northern Great Plains in the 1930's stimulated efforts to re-grass this area, where millions of acres of grassland had been plowed under and put into grain production to help meet the demand for food occasioned by World War I. Difficulty was experienced in obtaining stands of adapted grasses and it appeared that diseases were responsible, at least in part, for the failures to establish grass stands. Disease studies were initiated in this region, therefore, in cooperation with the Division of Cereal Crops and Diseases, the Division of Dry Land Agriculture, the Soil Conservation Service, and the North Dakota Agricultural Experiment Station.

The results of these studies were published in The Plant Disease Reporter in 1943 and 1946. It was shown that the main cause of the seedling blight of grasses in the Northern Great Plains is the fungus Pythium arrhenomanes Drechs. Certain other fungi, including Helminthosporium sativum Pam., King, & Bakke, Pythium debaryanum Hesse, P. ultimum Trow, P. irregulare Buis., and Fusarium scirpi Wollenw. var. acuminatum (Ell. & Ev.) Wr. were found to sometimes cause the grass seeds to rot in the ground and thereby reduce the stand.

In 1948, Gloeosporium bolleyi Sprague was reported to occur commonly on the roots of many species of grasses and cereals in the Western United States and proof was presented of its ability to cause seed rot and root necrosis.

Attempts to control pre-emergence seed rot and seedling blight by the use of such soil amendents as fertilizers and chemicals gave little encouragement, and seed treatments proved of little value except in inhibiting seed-borne fungi. It was observed that cool-temperature grasses, such as Russian wild rye, crested wheatgrass, and smooth brome, escaped seedling blight to a large extent if fall-seeded. The ability of certain of the fungi involved to persist in the soil for a period of years makes crop rotation of questionable value as a control measure.

Claviceps paspali F. L. Stevens & Hall, the fungus causing ergot of Paspalum spp., has been isolated in pure culture and the cultures have been used in inoculation tests to determine the reaction of various species of Paspalum to ergot. As a result of these tests, seven species of Paspalum were reported as new hosts of this fungus in 1939. On the other hand, the following species and strains were inoculated repeatedly but no infection resulted: P. notatum (narrow leaf type from Paraguay and common local type from Georgia), P. lividum, P. malacophyllum (a strain from Tifton, Georgia, and one from Gainesville, Florida), and P. intermedium. One of these species, P. malacophyllum, has been used by the grass breeders in crosses with dallis grass, P. dilatatum, in an attempt to secure a pasture grass of the dallis grass type that is immune or highly resistant to ergot.

Later studies in cooperation with the Georgia Agricultural Experiment Station and the Georgia Coastal Plain Experiment Station that were published in 1948 reported the susceptibility of Bahia grass (P. notatum) to C. paspali. These studies were initiated in 1941 when it was observed at Tifton, Georgia, that highly sterile Paraguay x common Bahia grass hybrids were much more heavily ergotized than either parent. Experiments made subsequently showed that when unpollinated panicles of Bahia grass were inoculated by immersion in a suspension of ergot conidia many ergot sclerotia developed. On the other hand, inoculating 30 minutes after pollination resulted in the production of only a few sclerotia, and florets inoculated 24 to 48 hours after

effective pollination developed no sclerotia whatsoever. It was concluded from these tests that effective pollination resulting in fertilization and seed set soon renders the florets of Bahia grass resistant to ergot attack.

In a comparison of 27 male sterile Bahia plants and a similar number of male fertile sister plants made in 1942, 33.1 percent of the male sterile florets but only 9.6 percent of the male fertile florets contained ergot sclerotia. Since the male sterile and male fertile plants should have been genetically the same, except for the male sterility factor, the differences in the amount of ergot produced by each must have been due to their differences in male sterility. These results suggest that in breeding for ergot resistance in grasses, care must be exercised lest differences in ergot readings due to sterility differences be mistaken for genetic differences.

Sclerotia of Claviceps paspali that had overwintered on the surface of the soil at Arlington, Virginia, were found capable of germination at any time during the following summer. It would appear, therefore, that infection can take place at any time during the summer that the Paspalum species are in flower. Many kinds of insects were observed to feed on the ergot "honey dew" and some of these insects were able to transmit the disease to healthy heads of dallis grass enclosed in celluloid cages in the greenhouse. It would appear from these observations and tests that insects play an important part in the dissemination of ergot of Paspalum.

In 1939, sclerotia of Claviceps yanagawaensis Togashi were found in seed of Japanese lawn grass, Zoysia japonica, imported from Japan. Since this fungus had not previously been reported from the United States, there appeared to be danger of introducing a new grass disease into this country. It was found that treating the seed containing ergot sclerotia with a 75 percent solution of sulphuric acid from 20 to 30 minutes killed the ergot sclerotia, whereas, the germination of the seed was improved by this treatment. It appears, therefore, that such treatment would provide an effective method of eradicating ergot sclerotia from imported grass seed.

A disease similar to ergot in that it affects only the seed of the grass plants and results in a lowered germination is the "blind seed" disease of perennial ryegrass that occurs in some sections of the Willamette Valley in Oregon. Intensive investigations of this disease have been in progress since 1943 in cooperation with the Oregon Agricultural Experiment Station and the results obtained in this study are summarized in a later section of this paper.

Approximately 200 species of fungi cause leafspots on grasses. Some of the more aggressive parasites occur in the genera Helminthosporium and Septoria and studies made to date have been largely restricted to these because of their greater economic importance. Reference has been made earlier in this paper to the fact that Helminthosporium sativum Pam., King & Bakke is one of the fungi causing pre-emergence seed rot and seedling blight of grasses in the northern Great Plains. Other Helminthosporium diseases that have been studied are the brown leaf spot of smooth brome grass and the leaf blight of Sudan grass.

Studies of the brown leaf spot of smooth brome grass (Bromus inermis) were undertaken in cooperation with the Wisconsin Agricultural Experiment Station in 1941 and the results of these studies were published in 1945. This disease is characterized by small, dark brown, scattered specks on the young leaf blades. A yellow halo develops around each spot and both spots and halos increase in size until coalescing lesions form large yellow patches on the leaf. Eventually, the entire leaf yellows and withers from the tip downward. The conidiophores of the causal fungus, Helminthosporium bromi Died. are produced on the brown spots or generally over the surface of the withered leaf. Conidial production, however, is extremely sparse and it was concluded from these studies that conidia play a minor role in the spread of the disease.

The ascigerous stage of the fungus develops in the infected leaves during the summer but mature ascospores are not produced until the following spring. The overwintered perithecia provide ascospores for the initial infections very early each spring and remain as sources of inoculum throughout the spring season. The ascigerous stage of the fungus was identified as Pyrenophora bromi Drechs.

Host range studies made during this investigation included six grasses and four cereals common to Wisconsin, but only smooth bromegrass developed typical brown-spot symptoms and produced lesions from which the fungus could be reisolated. Inbred lines of this grass differed markedly in their reaction to brown spot. Some lines were completely susceptible, while others were highly resistant, indicating that breeding for disease resistance should provide an effective control. Attempts to isolate the causal fungus from seeds collected from the panicles of heavily infected plants were unsuccessful, and it was concluded that the fungus is not seed-borne.

Foliage diseases of Sudan grass (Sorghum vulgare var. sudanense) occur throughout the eastern half of the United States and in many years materially reduce the yield and quality of the forage. Leaf blight, caused by the fungus, Helminthosporium turcicum Pass., is one of the

most widespread and common of these disorders. The characteristic symptoms of leaf blight are large linear to irregular lesions on the leaf blades, often extending into the leaf sheaths. The lesions are first water-soaked, then light olivaceous to brown, and finally straw colored as the tissues dry out. Narrow bands of reddish-brown pigmentation often occur along the margins of the lesions. Conidia are produced abundantly on the older portions of the lesions and cause new infections. The floral bracts of Sudan grass are frequently infected and work at the U. S. Regional Pasture Research Laboratory showed that the fungus occurs in the seed and glumes of a high percentage of Sudan grass seed lots.

In addition to attacking Sudan grass, H. turcicum causes a serious leaf blight of corn and occurs also on sorghum and Johnson grass. The results of inoculation tests with cultures from these four hosts were reported in 1945 and demonstrated the existence of four distinct parasitic races of the fungus. Two cultures from common Sudan grass and one from Atlas sorghum were pathogenic on Sudan grass and Gooseneck sorghum, but all three failed to infect corn. Four cultures from corn infected common Sudan, while two did not, but all six were highly pathogenic on corn. The culture from Johnson grass caused heavy infection only on Johnson grass.

Since the susceptibility of Sudan grass to foliage diseases was recognized as a limiting factor in its production in the warm, humid regions along the South Atlantic and Gulf coast, breeding for disease resistance was one of the principal objectives in a program of Sudan grass improvement undertaken in 1936 in cooperation with the Georgia Coastal Plain Experiment Station and the Georgia Agricultural Experiment Station. In that year, a number of selections and commercial varieties of Sudan grass from the Middle West were grown at Tifton, Georgia, for comparison with common Sudan. All seemed equally susceptible to foliage diseases but Leoti sorghum which was included in this nursery proved to be highly resistant. A number of hybrids were made, therefore, between the most desirable types of Sudan grass and the disease-resistant Leoti sorghum.

The F_1 plants of these hybrids were grown in the greenhouse the following winter and enough seed was obtained to grow approximately 35, 000 F_2 plants in the field in 1937. Six coarse-stemmed plants which seemed to possess the disease resistance of the Leoti parent were selected from this population and were back-crossed to some of the best individuals in a Sudan selection nursery in order to obtain a finer stemmed grass more like Sudan. These backcrossed hybrids were grown in the greenhouse the following winter and enough seed was obtained to grow approximately 30, 000 F_2 plants in the field in 1938. Only one individual was found in this planting which possessed the disease resistance of the Leoti parent and the vegetative characters of Sudan grass.

This resistant plant was moved to the greenhouse and there produced enough selfed seed to permit planting a 500-plant progeny test in the field in 1939. Study of this progeny revealed that this selection was breeding reasonably true for both disease resistance and the vegetative characteristics of Sudan grass. An isolated seed-increase block of this strain was planted at Tifton, Georgia, in 1940, but the very low seed yield obtained demonstrated the desirability of increasing the seed supply in one of the southwestern States producing Sudan grass seed. Arrangements were made, therefore, to increase the seed of this new strain at Lubbock, Texas, and 2, 200 pounds of recleaned seed were produced at this location in 1941. The new strain was given the name Tift Sudan and the Texas-grown seed was distributed for widespread testing in 1942.

These tests showed that throughout the Eastern United States, Tift Sudan is much more resistant to leaf blight than are the other strains of Sudan grass. It also possesses resistance to anthracnose, caused by Colletotrichum graminicolum (Ces.) G. W. Wils., and to two bacterial foliage diseases (stripe and streak).

Studies reported in 1944 showed that it is subject to attack by a previously unreported species of Helminthosporium that causes a leaf spot on Tift Sudan quite similar in appearance to that caused by H. maydis Nisikado and Miyake on corn. In 1948, this disease was given the common name of "target spot" and the causal fungus was described and named Helminthosporium sorghicola Lefebvre & Sherwin. So far, the new disease has not affected field plantings of Tift Sudan seriously and this grass has been acepted generally as a superior new variety in the eastern United States. It is also being used as disease-resistant parent in attempts to further improve Sudan grass in most State experiment stations where Sudan grass breeding programs are underway.

Cooperative work on Sudan grass improvement between the Texas Agricultural Experiment Station and the Bureau resulted also in a successful combination of the desirable characters of Sudan grass and those of the sweet sorghum variety Leoti. By crossing, backcrossing to Sudan,

and selecting over a period of years, a variety named Sweet Sudan was developed. This new variety possesses the sweet and juicy stem, the distinctive sienna glume color, and the resistance to shattering of the Leoti parent combined with the growth habit and production of common Sudan grass. Since this selection was made in a drier climate where foliage diseases are not as severe as in the Southeastern United States, Sweet Sudan is not as resistant to these diseases as is Tift. Breeding is being continued, therefore, for improvement in the resistance of Sweet Sudan to foliage diseases. A combination of the many desirable characteristics of Sweet Sudan with the disease resistance of Tift should provide a variety of Sudan grass much superior to any now being grown.

In 1947, as a result of the cooperative work with the Division of Cereal Crops and Diseases and the Mississippi Agricultural Experiment Station, a leaf spot of corn, sorghum, Sudan grass, and Pearl millet (Pennisetum glaucum) that occurs in the Southern United States was described and the causal fungus was identified as Helminthosporium rostratum Drechs. This appears to be primarily a disease of corn and Pearl millet since none of the sorghums or sorghum relatives tested were very susceptible.

Numerous species of Septoria cause blotches on the leaves of cereals and grasses and sometimes cause defoliation and reduce seed yield. The irregular blotches are straw-colored to brown and bear dark-brown to black pycnidia on the older portions of the lesions. The conidia (pycnospores) borne in these structures are predominantly at least ten times as long as broad, are hyaline to chlorinous, nonseptate to multiseptate, straight to curved, and are fusiform, filiform, or scolecosporous in shape. A detailed description of many of the species and varieties of Septoria that attack grains and grasses in the Western United States was published in 1944 as a result of studies of their life history and taxonomy made in cooperation with the Division of Cereal Crops and Diseases and the Oregon and Washington Agricultural Experiment Stations.

In 1940, during the course of the above studies, those species with nonseptate, falcate pycnospores borne in small globose pycnidia were transferred to the genus Selenophoma. The more important grass parasites placed in this genus are Selenophoma bromigena (Sacc.) Sprague & A. G. Johnson which causes leaf blotch of smooth bromegrass, and S. donacis (Pass.) Sprague & A. G. Johnson which attacks Arundo donax and a number of other grass species. In 1943, the Septoria-like types on grasses with broader pycnospores that are multiseptate and yellowish-brown to light-brown in color were transferred to the genus Phaeoseptoria. The fungi placed in this genus occurred in most cases on languishing leaves of various grasses and appeared to be semi-saprophytes of little economic importance. These studies have provided new information on a considerable number of grass parasites and have emphasized the complexity of the group of pycnidium-forming fungi that cause spots or blotches on the leaves of grasses.

TURF DISEASE INVESTIGATIONS

Studies of turf diseases and their control have been conducted by the Division in cooperation with the United States Golf Association Green Section over a period of approximately 20 years. Three types of control measures have been investigated: (1) the use of disease-resistant strains of grasses; (2) the employment of correct cultural practises; and (3) the use of fungicides.

The results of these investigations were published in The Bulletin of the United States Golf Association Green Section for August 1932. This publication has been of great value to greenkeepers and others responsible for the maintenance of turf.

Most of the experimental work on turf disease control was conducted on the plots making up the turf garden at the Bureau's Arlington Experiment Farm prior to the entry of the United States into World War II. With the abandonment of the Farm for agricultural purposes at that time, intensive work on turf diseases was terminated and has not since been resumed. Considering the vast sums that are expended annually on the establishment and maintenance of lawns around homes and public buildings, in parks and cemeteries, on playing fields and golf courses, on airfields and military installations, and along roadsides, it seems that more adequate public support for the investigation of control measures for turf diseases would be justified.

BLIND SEED DISEASE OF PERENNIAL RYEGRASS

A history of the work done on the blind seed disease since its presence in the United States was first recognized in 1943 is presented as a separate section of this paper, since it is felt that it illustrates very well an instance in which forage crops disease investigations have been

of immediate practical value to growers. Such instances are not numerous in this field of work, since in most cases control must be sought through the development of a disease-resistant variety in cooperation with a forage breeder. As a rule, approximately ten years are required to reach such a goal and sometimes it requires nearly 20 years.

Low germination of the seed of perennial ryegrass, Lolium perenne, produced in sections of the Willamette Valley in Oregon was first noted in 1941. More extensive difficulties were experienced in 1942 while in 1943 approximately one-fourth of the seed crop could not be certified because of less than 85 percent germination and it appeared that commercial seed production of this grass in the area was doomed. During the winter of 1943, it was established that the difficulty was due to the blind seed disease caused by the fungus Phialea temulenta Prill. & Delacr. and studies were undertaken in cooperation with the Oregon Agricultural Experiment Station. This disease had been shown previously to be responsible for low germination of the seed of perennial ryegrass in New Zealand, Ireland, and Scotland.

The seed is the only part of the plant infected by this fungus, which overwinters in infected seed that has fallen on the ground. Apothecia are produced in the spring coincident with the flowering of the grass and the ascospores produced in these fruiting structures initiate the primary infections. Conidia are produced abundantly in a slimy matrix on infected seeds during the spring and spread the infection to additional flowers, thus producing an epidemic.

The first apothecia of this fungus ever seen in the United States were found in Linn County, Oregon, in May 1944. Apothecia have been found in abundance since then on seeds of perennial ryegrass and darnel (L. temulentum), and on a few old seeds of Hordeum gussoneanum.

Workers in New Zealand had reported that no apothecia were obtained from two-year-old-seed, and based on this information, the planting of such seed was recommended to Oregon growers during the winter of 1943. While the planting of aged seed, or of disease-free seed, is an excellent control measure, it cannot provide more than partial control when the disease is left unchecked in nearby fields, because of the natural spread of the disease by ascospores.

A service for growers of ryegrass seed in New Zealand provides for examining head samples for infestation before harvest to enable the growers to avoid the expense of harvesting worthless seed crops. A modification of the New Zealand method of pre-harvest testing was tried in Oregon on a rather extensive scale in the summer of 1944. While this method was found to give reliable estimates of field infestation, it did not appear to be of much value to growers in Oregon, since perennial ryegrass is grown extensively in that State in pure stand and primarily for a seed crop. In New Zealand, on the other hand, white clover and perennial ryegrass usually are grown in pasture mixtures, and if the ryegrass seed crop is found badly diseased in pre-harvest tests, the grower may either cut the field for hay or save it for a later clover seed crop. His loss is, therefore, comparatively light when compared with that suffered by an Oregon seed grower. Further, there is an apparent weakness in this system in that it leaves heavily infested fields as sources of abundant inoculum for reinfestation of old fields and possible infestation of new fields.

Pre-harvest testing of head samples was discontinued in Oregon, therefore, after one season's trial and was replaced by a seed testing service. Seed samples from every perennial ryegrass seed production field in Oregon that had been entered for certification were examined for the presence of the conidia of the blind seed fungus during the winter of 1944. In making the examinations, glass vials of approximately 18 ml. capacity were used to measure the seed which was placed with the same amount of water into a 250 ml. Erlenmeyer flask. After soaking for 20 minutes, the water was strained from the seeds and a drop of the suspension was placed on a microscope slide for a conidial count. A Bausch and Lomb haemacytometer with Nebauer ruling was used to standardize the method. After making numerous conidial counts and comparing the results with the germination of the respective seed samples, eight classes of infection were set up to classify individual samples.

The degree of infection in seed samples that would result in a germination below 85 percent in the next crop was estimated to be the Light class of infection, i.e., those having 7 to 15 conidia per 1/160 cu. mm. If the seed samples showed this amount, or a heavier infestation, the fields were regarded as unprofitable for another year and it was recommended to the grower that such fields be plowed before May 1, 1945, since apothecial production was known to begin early in May. This recommendation was rather generally followed after it was explained to the growers that they would profit by cleaning up such fields and returning them to production and that leaving such infested fields would constitute serious hazards to neighboring fields that were still producing good seed.

Fields whose seed samples revealed a Very Light class of infection, i.e., those having 4 to 6 conidia per 1/160 cu. mm., were regarded at first as probably safe for another year's seed

production. Experience soon revealed, however, that fields with a Very Light infestation were likely to produce seed of poor germinability, if the field were poorly drained and likely to be wet in May and early June. It was, therefore, recommended that such fields also be plowed.

During the years this program of disease control has been in operation, there has been a gradual elimination of diseased fields, and an increase in fields without any blind seed disease. It appears that if the growers will continue to cooperate in this program, the disease may be practically eliminated as a limiting factor in perennial ryegrass seed production in Oregon.

BROWN STEM ROT OF SOYBEAN

Although only a few soybean fields infected with brown stem rot were observed in Central Illinois in the fall of 1944, this disease occurred in severe epidemic form in Central Indiana, Illinois, and Iowa in 1945. Complete loss of yield occurred in some fields and damage in some entire counties in Central Illinois was estimated as 10 percent. The disease is now recognized as one of the most important diseases of the soybean crop throughout Illinois and is becoming increasingly important in Indiana, Iowa, Missouri, and Ohio.

The first symptom of brown stem rot usually appears in July or early August. At this time infected plants show no external evidence of the disease, but if the stems are split longitudinally a brown coloration of the pith and vascular elements is observed extending upward from the base of the stem. In seasons which are unfavorable for the development of the disease, only the internal stem symptoms occur. Under conditions favorable for disease development, a sudden blighting and drying of the leaves occurs in late August or early September. The leaf tissues adjacent to the veins remain green while the interveinal portions die. As a result of the extensive blighting of the leaves, a badly infected field appears brown from a distance as contrasted with the yellow-green of a normally maturing field. In advanced stages the outside of the stem turns brown and the plants lodge badly because of the extensive internal rotting. It is the lodging of the plants and the resultant mechanical difficulties in harvesting that are responsible for the substantial losses caused by this disease. Weather conditions at harvest time, therefore, are of extreme importance in determining the amount of loss that occurs.

A fungus that produced a dense, putty-colored, non-fruiting mycelial growth on culture media was readily isolated from the diseased plants and was proved by inoculation tests to be the cause of the diseased condition. Since the fungus did not produce a spore-bearing stage on the diseased soybean plants and no fruiting was observed on culture media, identification of the causal organism was impossible. Studies were undertaken, therefore, on methods for inducing sporulation by this fungus.

The results of these studies, conducted in cooperation with the Division of Cotton and Other Fiber Crops and Diseases and the Mississippi Agricultural Experiment Station, were published in 1947. In this work it was found that the fungus produced conidia sparsely on potato-dextrose agar, oatmeal agar, and potato-dextrose-raisin agar and that the spores could be suspended readily in sterile water by gently flooding the surface of a two-month-old culture. These spores germinated readily when planted on 2 percent water agar and conidiophores and conidia were produced abundantly in 8 to 10 days at room temperature. Cultures younger than two months were induced to fruit also by dividing a small portion of the mycelial mat very finely and placing the fragments on water agar. From the characteristics of the conidiophores and conidia, the fungus was identified as a species of *Cephalosporium*.

More detailed studies of this fungus and the disease have been conducted at the U. S. Regional Soybean Laboratory in cooperation with the Illinois Agricultural Experiment Station. The results of these studies were published in 1948. In this work, a large number of vegetable decoctions in 2 percent agar and with and without dextrose, were tested as media for inducing sporulation.

Conidia were produced on string-bean agar, rice polish agar, cucumber agar, and soybean-stem agar. The addition of 2 percent dextrose to the above media inhibited sporulation. Spore production was best on the soybean-stem agar, the spores appearing after five days at 20^{o} C. Spore germination studies showed that the optimum temperature range for germination was 21^{o} to 25^{o} C.

Since the fungus *Cephalosporium acremonium* Cda. had been reported in 1924 to produce a systemic infection of corn in the Midwest that was characterized by blackened vascular bundles in the corn stem, the brown stem rot fungus of soybean was compared very closely with it. Cultural and morphological differences between the two fungi were immediately evident and cross inoculation tests showed that the two were pathologically distinct. Since the brown stem rot fungus did not seem to conform to the description of any species of *Cephalosporium* previously published, it was concluded that it was a new species and the name *C. gregatum* Allington &

Chamberlain was proposed. This specific name was suggested by the most outstanding characteristic of the fungus in culture, i.e., the aggregates of short, straight or club-shaped conidiophores.

Attempts to isolate the causal fungus from seed harvested from diseased plants have all been unsuccessful, indicating that it is not seed-borne. It has been demonstrated, however, that the fungus can exist for more than a year in moist soil stored in the greenhouse. Further, plants grown in naturally infested soil under the proper environmental conditions readily become infected and thereby supply a reliable criterion for the existence of the parasite in the soil. It appears that in the field, therefore, the roots are the most common points of entry and that the fungus progresses from the roots upward through the water-conducting vessels of the stem, lateral branches, and petioles.

The effect of soil and air temperature on the incidence and development of the disease were studied in the greenhouse. While the disease did not appear to be particularly responsive to different soil temperatures in these tests, the response to air temperatures was quite striking. When inoculated plants were grown at an air temperature of 15° C., the internal browning of the stems was evident 8 to 10 inches above the point of inoculation and typical leaf symptoms of the disease were observed within two or three weeks. At 21° C., on the other hand, progress of the infection was almost inhibited and at 27° C., no spread of the fungus in the plants was observed. These results offer an explanation of why the disease develops very slowly under the high temperature conditions of mid-summer, then develops with great rapidity with the occurrence of a few cool days and nights in the autumn.

In limited host range studies, soybeans and the mung bean (Phaseolus aureus) were the only plant species shown to be susceptible to attack by the brown stem rot fungus.

In September 1946, an aerial survey was made to locate brown stem rot-infested soybean fields in Central Illinois. The overall brown color caused by the dead leaves in the later stages of the disease contrasts sharply with the yellow-green of normally maturing fields, thus making identification by aerial observation possible. From the air it was observed that certain fields were only partly diseased and that a sharp line of demarcation separated the diseased and healthy portions of such fields. These fields were located on a detailed map while in the airplane and the farms were visited later by car. On these visits the diagnosis of brown stem rot was verified and the farmer was interviewed in regard to the history of the diseased and healthy portions of his field.

Within a period of two weeks, 35 such fields were investigated and completely reliable histories were available on 15 of these fields for a period of at least four years. Without exception, the information gained by this method indicated a crop rotation effect upon the incidence of the disease. The diseased portions of fields were found to have had different crop histories from the healthy portions in that soybeans had been grown much more frequently in short rotations, such as corn-soybeans-corn-soybeans. On the other hand, a four-year rotation of corn, soybeans, oats, and clover appeared to have controlled the disease satisfactorily on the farms studied. On the basis of these studies, it was concluded that one method of controlling brown stem rot in Illinois is to practice a crop rotation system which provides for three successive annual crops other than soybeans between soybean plantings. Studies in 1947 and 1948 have confirmed the value of four-year rotations in lessening the severity of the disease and reducing the losses suffered.

While crop rotation has been shown to be an effective method of controlling the brown stem rot disease in Central Illinois, it does not provide complete control nor offer a method of eradicating the causal fungus from the area. Intensive search is being made, therefore, for strains of soybeans that are resistant to the brown stem rot fungus.

Since no satisfactory method for the mass inoculation of soybean field plantings with brown stem rot has been developed, natural infection must be depended on in testing for resistance to this disease. In 1947 and again in 1948, therefore, a farm field near Weldon, Illinois, where the soil is known to be infested with the brown stem rot fungus, has been used for growing an extensive soybean nursery in the search for resistance to this disease.

The 1948 nursery consisting of 1450 soybean introductions and varieties was planted at Weldon in May and disease ratings based on the density and height of internal browning in the stem were assigned in September. These ratings were made on a scale of 0 to 5, with 0 indicating no browning and 5 indicating dense browning throughout the stem. While all of this plant material was susceptible to the disease in some degree, differences in the extent and intensity of the browning were observed. Eleven of the soybean introductions showed only traces of browning (numerical rating 1), while many more showed light infection.

Further testing of this material in similar trials will be necessary to more fully evaluate

its resistance to the disease. It appears from the results to date, however, that within a few years strains of soybeans resistant to brown stem rot will be available to the soybean breeders for use in crosses. The object of these crosses will be the development of new, superior soybean varieties that will be resistant to the brown stem rot disease, thus providing a method of control far superior in many respects to the rotation practices now recommended for holding this disease in check.

SUMMARY

The plant disease research on forage crops conducted by pathologists of the Bureau of Plant Industry, Soils, and Agricultural Engineering over a period of approximately 35 years is summarized under the following sub-divisions: (1) Alfalfa; (2) Clovers; (3) Soybeans; (4) Lespedeza, Cowpea, and Miscellaneous Legumes; (5) Hay and Pasture Grasses, and (6) Turf.

Two forage diseases, i. e., the blind seed disease of perennial ryegrass and the brown stem rot of soybean, are given more detailed consideration in separate sections of the paper since they provide typical examples of current problems and the methods of investigation being employed.

The work summarized concerns 12 diseases of alfalfa, 13 diseases of clover, 9 diseases of soybean, 3 diseases of annual lespedeza, 3 diseases of cowpea, 5 diseases of Austrian winter pea, 3 diseases of vetch, 2 diseases of kudzu, 7 diseases of lupine, and 24 diseases of hay and pasture grasses. No specific diseases of turf grasses are mentioned in the brief summary presented of the cooperative work in this field.

The research work on forage crops diseases has been conducted in large part in cooperation with one or more of the State agricultural experiment stations, or other agencies, and such cooperation is recognized throughout the paper. This cooperation has frequently involved grass and legume breeders as well as forage pathologists, since control of most forage crops diseases must be sought in the development of disease-resistant varieties of the crops.

DIVISION OF FORAGE CROPS AND DISEASES

PLANT PATHOLOGY IN THE DIVISION OF RUBBER PLANT INVESTIGATIONS

J. B. Carpenter[1]

INTRODUCTION

History of the Division

The United States Department of Agriculture first expressed an interest in rubber-bearing plants about 1890 through its plant introduction activities. The first appropriation specifically for investigation of sources of rubber was an allotment of funds from a Commerce Department appropriation in 1923. This and the following annual appropriations (made directly to the Department of Agriculture) were assigned to the Division of Crop Acclimatization and Adaptation Investigations which later was renamed the Division of Cotton, Rubber, and Other Tropical Plants. In 1934, the rubber work was reassigned to the Division of Plant Exploration and Introduction. In 1940, a greatly expanded project for encouraging rubber production in the Western Hemisphere was authorized and placed tentatively under the administrative direction of the head of the Division of Sugar Plant Investigations. This project developed rubber investigations in cooperation with 14 Latin American countries. In 1942, this latter project and the work previously assigned to the Division of Plant Exploration and Introduction were combined into the present Division of Rubber Plant Investigations.

Program

The work of the Division proceeded along two parallel courses. The first of these was concerned only with studies on species of *Hevea*, principally *H. brasiliensis* (H. B. K.) Muell. Arg.; the second was concerned with the investigation of alternative, domestic rubber-bearing plants, both to supplement the production of rubber of the *Hevea* type, and to find, if possible, special purpose rubbers. The latter studies were centered primarily on guayule, *Parthenium argentatum* Gray, with attention also to the possibilities of the Russian dandelion, *Taraxacum kok-saghyz* Rodin, and goldenrod, *Solidago* spp.

Early Investigations

The earlier publications of the Department dealt mostly with taxonomic and production problems of rubber-bearing plants and it was not until 1923 that any important disease investigations were made. In that year, a survey was made of the South American Leaf Blight of *Hevea* rubbertrees caused by *Dothidella ulei* P. Henn. in certain Caribbean countries, and in the same year an extensive survey of the diseases of the *Hevea* rubbertree in the Amazon Valley was begun. About 10 years later, the scab disease of goldenrod, caused by *Elsinoë solidaginis* Jenkins & Ukkelberger, was the subject of investigations in the Southeastern United States, where it had assumed great severity on both the indigenous species and the selections under trial for rubber production.

SOUTH AMERICAN LEAF BLIGHT

Introduction

Disease Characteristics and Economic Importance: -- Concurrent with the increased interest in rubber production beginning in 1940, pathological problems immediately presented themselves as the several cooperative field stations were developed. The most important problems centered on the control of the South American Leaf Blight, which weakens and may kill plants of all ages through repeated defoliations, reduction of leaf surface, and cankering of young stems and petioles, with less frequent attacks on fruit pods and inflorescences. This disease had, up until the early 1940's, been a major factor in the failure to establish successful large-scale plantings of *Hevea* in tropical America. In British and Dutch Guiana and Trinidad, leaf blight destroyed thousands of acres of *Hevea* rubbertrees from 1910 to 1920, and later rubber-growing enterprises in Brazil, Panama, and Costa Rica were seriously handicapped by the ravages of the disease.

[1]Editor: Prepared cooperatively by the staff of the Division.

First Disease Surveys: -- The Department's surveys of this disease, begun in 1923, established its great economic importance as a limiting factor in the successful development of rubber plantings at that time, and its potentialities as a formidable pathological problem should the plantation industry be expanded in tropical America. These surveys gave a detailed report on the incidence of the disease in the countries visited--British and Dutch Guiana, Trinidad, Brazil, Bolivia, and Peru--and brought together for the first time all of the pertinent literature on leaf blight and its causal organism.

Recommendations for Disease Control: -- Methods for controlling the disease were considered in the survey reports, and the two principal recommendations, complemented later by the development of fungicidal control measures, became the basis for the control program when the rubber investigations group was organized almost two decades later. These recommendations were (1) the selection and development of disease-resistant types of Hevea, to be propagated vegetatively as clones, and (2) the strict enforcement of quarantine regulations on the movement of propagating stocks, either internally or internationally.

Thus, by 1940, the approach to the control of leaf blight had been established, although only partially developed. The protection of nursery and propagating stocks was a matter of great importance and urgency, which was met by the development of adequate fungicidal measures for spraying or dusting nurseries. At the same time, the selection and development of disease-resistant clones was undertaken and greatly facilitated by the cooperation of the Ford Plantations Company and the Goodyear Plantations Company, both of which had had such work in progress for many years. In addition to varying national quarantine requirements, the Department's representatives established and maintained strict procedures governing the shipment of propagating stocks.

Cultural Practices in Relation to Control: -- A brief consideration of the horticultural practices involved in rubber production is pertinent here to explain the procedures used in the control of leaf blight. High-yielding Hevea clones are propagated by bud-grafting them onto one-year-old seedlings. Thus, a young tree commonly consists of a seedling root stock with the above-ground part produced from a low budding. In the absence of clones that combine high yield with high blight resistance, the budding process may be carried one step further. Seedlings budded with a high-yielding, blight-susceptible clone may be top-budded with a blight-resistant clone at a height of approximately six feet, a procedure made feasible because the yield of a tree is determined largely by the trunk or tapping-panel clone. The double-budding operation offers a real advantage as it permits selection of the tapping-panel clone almost solely on the basis of yield, whereas the crown clone may be chosen on the basis of resistance to disease and insect pests, and resistance to wind damage.

Fungicidal Control

Methods and Materials: -- Turning to a consideration of the fungicidal control measures evolved, earlier sporadic spraying experiments were unsuccessful. However, equipment and materials for a thorough investigation of the subject of fungicidal control of leaf blight were assembled soon after the program of rubber investigations was launched in July 1940. In October of that year, spraying and dusting experiments were started in young seedling nurseries on the Goodyear Rubber Plantation in Panama. During previous years, more than 90 percent of the seedlings planted in some of the nurseries there had been destroyed by leaf blight.

The spraying tests in Panama were conducted under hot moist conditions that induced constant emergence of young susceptible foliage and frequent infection periods for leaf blight. This allowed little opportunity for unprotected plants to escape the disease; therefore, the results of these tests were soon obvious, and they have proved to be reliable.

Tests with various types of spray equipment have shown that power-driven pumps are most efficient for spraying large nurseries. However, in the case of young plants growing at field spacing, knapsack sprayers are the most efficient type.

Copper Fungicides: -- Bordeaux mixture, prepared according to a number of formulae, was used in the first spraying tests. It gave excellent blight control, but often injured very young plants. High-lime Bordeaux caused more injury than low-lime Bordeaux. The "insoluble" copper fungicides, proprietary products sold under a number of trade names, gave excellent disease control without injuring young plants. Subsequently, spray mixtures containing 2 pounds of "insoluble" copper fungicide and a small amount of spreader and sticker per 100 gallons of water have been used to protect millions of disease-susceptible seedlings growing in nurseries from Mexico to Brazil and Peru. Sprays applied at a maximum frequency of once or twice per week have frequently controlled leaf blight.

Sulfur and Organic Fungicides: -- Lime-sulfur, when used at concentrations high enough to control the disease, burned Hevea leaves during periods of bright hot weather. Colloidal and dry-wettable sulfurs caused little or no damage to Hevea foliage but were less effective than "insoluble" copper fungicides in controlling leaf blight.

In addition to the older copper and sulfur fungicides, a variety of new organic materials were used in these experiments. Some of the organic fungicides were less effective than colloidal sulfur, whereas others were almost as effective as the "insoluble" copper fungicides.

Spreaders and Stickers: -- Preliminary trials indicated that spreaders and stickers, such as rosin, casein, flour, oils, and a number of proprietary products, were essential for the deposition and retention of the fungicides, in view of the waxy nature of Hevea foliage and the frequency of tropical rains. Spreaders and stickers generally improved disease control, but the oils caused severe stunting of plant growth. Rosin and casein preparations gave the most satisfactory results.

Dusting: -- Both copper and sulfur dusts gave partial disease control. The degree of control, however, was less than that obtained by spraying with similar fungicides.

Influence of Fungicides on Budding Success: -- Recent studies have shown that the choice of fungicides may influence budding success. When copper fungicides are applied frequently to budwood gardens, the bud patches derived from those plants may give low budding success, through some deleterious effect of the fungicidal residues. This effect, however, can be largely eliminated by washing with water prior to removing the bud patches. For this reason, it has been recommended that certain effective organic fungicides be used for budwood gardens. Within the last few months, investigations on the Diplodia disease of bud grafts in Mexico have indicated that the same organic fungicides are the most effective in preventing this disease, thereby giving further impetus to the use of these materials for general nursery spraying.

Control in Relation to Cultural Practices: -- Success in controlling leaf blight by spraying seedling nurseries encouraged tests in spraying high-yielding, blight-susceptible clones until they reached top-budding size. After seedlings are budded with blight-susceptible clones, they may be transplanted to the field immediately or they may be grown under spray in the nursery until they are top-budded. The more desirable procedure will depend upon local conditions, especially favorable soil and rainfall, to insure survival of transplanted top-budded stumps.

In many localities, young susceptible budded plants growing at field spacing are not severely attacked by leaf blight during the first year (required for reaching top-budding size) and need no protection from sprays. In other localities, weekly or more frequent spray applications may be necessary. Even with this number of applications, spraying is a cheap protection because only the young susceptible leaves need be sprayed and, of course, all spraying is discontinued after the trees are top-budded with resistant clones.

From the beginning, blight control by spraying large plantation trees was not considered economical. Spraying, however, does have still another practical application in protecting high-yielding, blight-susceptible clones growing in mixtures with highly resistant clones in breeding gardens. The feasibility of preserving valuable breeding trees by spraying with fungicides was demonstrated by tests conducted in Panama.

Disease Resistance

Methods and Materials: -- Studies on disease resistance were initiated concurrently with tests on fungicidal control of leaf blight. This phase of the program was greatly facilitated by the pioneer selection and breeding work of the Ford and Goodyear Companies. An intensive search for high-yielding blight-resistant jungle trees was begun, and the program of crossing high-yielding Oriental clones with blight-resistant indigenous selections was augmented by personnel working under the intergovernmental agreements, whereby this Government and the cooperating Latin American Republics arranged for the interchange and testing of propagating materials for mutual benefit.

Several hundred clones showing high resistance to leaf blight have been selected after intensive resistance tests at Turrialba. These clones originated from the highest yielding seedling trees on the Ford Plantations, outstanding jungle trees, and special seed collections from widely separated parts of the Amazon Valley. In addition, the number of blight-resistant selections has been increased constantly by an extensive breeding program.

Prior to the development of adequate resistance testing, thousands of acres of susceptible and slightly resistant Hevea trees were planted at field spacing in or near blight-infested areas. Many of these plantings grew well for two, three, or four years before they were destroyed by

increasingly severe attacks of leaf blight. This resulted from increasingly favorable conditions for development and spread of the disease, brought about by the development of the trees from slender, unbranched stems to many-branched, interlacing crowns. To prevent the recurrence of these destructive attacks, a method for testing and selecting clones was developed, using testing plots which provided near-optimum conditions for blight development at the Cooperative Rubber Plant Field Station at Turrialba, Costa Rica. A study of the means of spread and behavior of leaf blight contributed to this work.

Resistance Testing Methods: -- The main disease-testing center was developed at Turrialba, located in a valley 2,000 feet above sea level and subject to frequent mists and heavy night dews. On most nights during the year, *Hevea* foliage remains wet at least 10 hours, which is long enough for blight spores to germinate and infect the young foliage of susceptible plants. The tests consisted of growing heavily-diseased seedlings in alternate nursery beds with the clones and selections to be tested for resistance, thereby subjecting them to a constant and abundant inoculum. This combination of conditions allowed little opportunity for disease escape, and observations on a large number of clones have shown that the damage sustained by plants growing in the Turrialba plot for six or eight months is comparable to the heaviest damage suffered by the same clones growing to maturity in dense plantation stands.

Classification of Selections: -- An interesting aspect of the disease-resistance studies was the development of a practical system of classifying *Hevea* clones for resistance, enabling trained technicians to make independent, uniform observations. Disease resistance may be exhibited either as resistance to leaf damage and defoliation, or as partial to complete inhibition of fungus sporulation. The second character is fully as consistent as the first, and much evidence shows that it should receive equal or even greater weight in selecting plants for resistance. Under the testing conditions explained above, maximum opportunities are given for infection. Being a long-term crop, *Hevea* rubber must be sufficiently resistant to withstand leaf blight under environmental conditions most favorable for disease such as occur in constantly growing and changing field plantings over a period of many years. The severest disease damage induced on plants growing in test plots is therefore accepted as the most reliable measure in predicting the long-term behavior of a clone.

The system of classification provides 10 classes for leaf damage and defoliation, and 5 classes for sporulation. As an aid to visualizing the system as a whole, the resistance classes may be grouped as follows: classes 1 and 2 are composed of practically immune clones; classes 3 to 6 are characterized by necrotic lesions and damage in ascending order; classes 7 and 8 show defoliation; and classes 9 and 10, dieback and death. In general, clones receiving low susceptibility ratings show little or no sporulation, whereas those with high susceptibility ratings show moderate or heavy sporulation. None of the class 1 and 2 plants studied has shown any sporulation, and all class 9 and 10 plants have shown heavy sporulation. Clones falling into classes 3 to 8, however, have not been so consistent, and certain clones in classes 4 or 5 have shown heavier sporulation than some in class 7 or 8. Each clone, therefore, receives a separate rating for resistance to damage and degree of sporulation.

Clones that have received disease ratings of 1 to 5, which bear non-sporulating to sparsely sporulating lesions, are considered entirely safe for use in field plantings. Clones that have similar ratings for sporulation but have fallen into classes 6, 7, and possibly 8, may be used in mixed plantings with more resistant clones. Regardless of the rating for resistance to leaf damage, clones showing heavy sporulation should not be used in field plantings and those with even moderate sporulation should be used sparingly, if at all.

Regional Tests on Variability of the Fungus: -- Considering the sensitivity of the fungus to weather conditions, together with regional variation in disease severity observed in plantings of the several cooperating countries, reliable selection work necessitated thorough resistance tests in more than one locality. Groups of clones from several widely separated areas of the native habitat of *Hevea* are being grown under comparable exposure to blight in regional test plots in Costa Rica, Panama, Trinidad, Brazil, and Peru. Likewise, large populations of *Hevea* seedlings from jungle trees are being tested at the place of their origin and in other areas. Both clones and seedlings that have proved highly susceptible in some areas have been damaged slightly or not at all in certain other areas. Prolonged exposure, however, has brought many cases of increased severity as variants of the fungus appear. Some clones have proved highly susceptible to certain variants only, and still others--now recommended for commercial use--have been highly resistant in all areas.

Results of the Resistance Studies: -- The use of thoroughly tested blight-resistant clones for top-budding high-yielding but susceptible Far Eastern clones has now become standard procedure. In blight-infested areas, fungicidal sprays are used to control the disease on

susceptible seedlings and Far Eastern clones until they are budded with resistant clones.

Following several years of study, it is now feasible, in some areas, to produce three-component trees (seedling rootstock, high-yielding panel, and disease-resistant top) on a nursery basis, distributing them thereafter for field plantings. This will be of great importance from the standpoint of disease control, as it will prolong the period that fungicides may be applied at reasonable cost and, in the case of leaf blight, will eliminate the possible need for field spraying. By maintaining the plants in a healthy, vigorous condition, the time required for completion of the double budding process is substantially shortened.

PELLICULARIA LEAF SPOT

Th· Pellicularia leaf spot disease of the Hevea rubbertree caused by Pellicularia filamentosa (Pat.) Rogers was first recognized in Brazil in 1943, and possibly a year earlier in Peru. In Brazil it had apparently been observed, though not recorded, some time prior to this and had been causing considerable damage. It has been reported once from Colombia and twice from Costa Rica, being a minor disease in both instances. During 1945, this disease assumed epiphytotic proportions in the Peruvian rubber plantings and a pathologist was assigned by the Division to Peru in 1946 to study the control and epidemiology of the disease.

Characteristics of the Disease: -- This disease is one of the "Rhizoctonia" leaf blights and initiates its attack on immature foliage, causing under favorable disease conditions severe defoliation of young plants. It may be a limiting factor in the production of propagating stocks if allowed to go uncontrolled.

Characteristically, the disease first appears on young expanding leaves as small cleared areas, on which appear few to many drops of exuded latex. Depending upon the clone, the latex may darken rapidly. If favorable disease conditions persist, within a few days the fungus begins to make a rapid radial superficial growth on the lower surface of the leaf, followed by discoloration of the older tissues and the production of more or less concentric rings, chalky to buff in color and temporarily interspersed with green tissue. Growing at a rate of several millimeters per day, the leaf spot or spots soon cause defoliation of the affected leaflets. The older portions of the lesion may bear an extensive sporulating surface, which appears as a silvery bloom.

Dry weather strongly inhibits the disease and the lesions are promptly delimited. Upon prolonged drying, the necrotic areas shatter, giving a shot-hole or ragged effect. In contrast to leaf blight, this is typically a debilitating and not a fatal disease.

Complementary Studies on Plant Growth: -- Detailed information on the growth of young rubber plants was sought to provide a basis for interpreting the results of control studies and information pertinent to the selection of disease-resistant clones. The development of the flush and its foliage was followed through several consecutive months in various studies. These showed that at Tingo Maria vigorous clonal or seedling plants produce a new flush about every six weeks, at least during the first year, and that the leaves of the flush require about three weeks to expand and assume their typical mature position. During the grand period of growth, the young leaf may elongate at an average rate of more than one millimeter per hour, with little difference in growth rate between night and day.

An eight-months study of artificial defoliation was also made, involving the removal of leaflets in multiples of 20 percent, to provide from no defoliation in the checks to complete defoliation in the most severe treatment. Young seedling trees were used and were protected by frequent spraying.

Production of Spores: -- Studies on the production and dissemination of basidiospores of the fungus led to the discovery that these are produced almost exclusively at night, beginning shortly after sunset. This mode of sporulation is so well developed that attempts to change the rhythmic production of spores by keeping the fungus in continuous light or darkness for prolonged periods failed to change its habits, though such treatments affected the quantitative production of spores. Inasmuch as the spores are freely discharged in enormous numbers, and considering the rate of spread of the disease, there can be little doubt that wind-borne inoculum is the chief means of dissemination.

Exploratory studies on the persistence of the fungus during prolonged periods indicate that it lives in refuse and soil, fruiting on damp surface debris. When conditions are favorable, the parasitic habit may be resumed.

Infection Studies: -- The time required for spore germination, infection, and incubation, and the period of susceptibility of the foliage were also examined. The data indicate that germination and infection occur in a few hours and that the lesions become apparent several days

later. The leaves are susceptible for only a few days. These studies were made in an improvised glass-roofed shelter to exclude rain and dew. Temperature and humidity were essentially the same as those prevailing outdoors.

Fungicidal Control: -- The development of control measures for protecting nursery and propagating stocks was of primary importance. Screening tests to determine the spraying, dusting, and phytotoxic properties of various fungicides and adjuvants began in June 1946 and beginning in October a comparison of ten spray and seven dust formulae was made over a four-months period.

It was found that weekly applications of sprays, carefully made, gave satisfactory control when insoluble copper, organic, or wettable sulfur fungicides were used. The better treatments reduced defoliation from about 40 percent to 2 percent or less, markedly reduced the incidence of infection, and caused most of the lesions that did develop to be delimited while small. The best dust treatment controlled leaf spot as well as the better sprays, but the other dust formulae were inferior, due principally to poor dusting qualities.

Disease Resistance: -- A Pellicularia disease-resistance trial area, similar to that described for leaf blight, was laid out in 1947 and the assembling of promising clones and selections begun. In addition to this, all of the nursery plantings in Peru were observed periodically, both the clone collections and the seedling populations, for possible disease-resistant individuals. The extensive collections of clones and seedling populations in Brazil were examined in 1948 and some breeding material was taken to Peru. To date, no resistant selections have been found in *Hevea brasiliensis*. *Hevea rigidifolia* (Spruce ex Benth.) Muell.-Arg., at present a non-commercial species with leathery foliage, appears to be highly resistant or immune. Fortunately, a few of the blight-resistant top-working clones are quite tolerant of the disease and make fair growth even under severe disease conditions.

Growth in Relation to Disease Control: -- Many years' observation of the disease by various investigators has led to the conclusion that the *Pellicularia* leaf spot is primarily a disease of nursery rubber plants, where it may seriously weaken the plants and render them unfit for rootstocks or clonal multiplication stocks. It also attacks the trees in the field until they begin to undergo annual leaf change at about three years of age. However, when leaf change begins, coinciding with the end of the dry season in Brazil and Peru where the disease is serious, the disease is at its lowest ebb and the new foliage is quickly formed and matured before infection can occur. Although some vigorous branches continue to make new, susceptible flushes throughout the year, the proportion of new foliage becomes progressively smaller so that by the third or fourth year after the onset of leaf change the disease becomes negligible.

OTHER PATHOLOGICAL INVESTIGATIONS

Other Disease Problems in Hevea Rubber: -- Other pathological problems associated with *Hevea* rubber culture are (1) the panel diseases which are important in areas coming into tapping; (2) the *Phytophthora* leaf, stem, and fruit disease which is an increasing problem in some areas; and (3) root disease which, though not serious at present, may be expected to increase in severity as the trees become older.

Diseases of Other Rubber-Bearing Plants: -- Pathological investigations on rubber-bearing plants other than *Hevea* have included intensive studies on certain diseases of guayule and the Russian dandelion. The most important groups of diseases on these crops are those caused by soil-borne fungi and include damping-off in seed-beds and root and crown rots associated with field plantings and stored propagating stocks. Foliage diseases and physiological disturbances have also received attention.

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DIVISION OF RUBBER PLANT INVESTIGATIONS

PLANT PATHOLOGY IN RELATION TO FEDERAL DOMESTIC PLANT QUARANTINES

W. A. McCubbin[1]

INTRODUCTION

The quarantine and regulatory field includes all those situations in the pest battle front where, in addition to individual effort, community cooperation, and technical aid and counsel, a control undertaking attempts to achieve more extensive or more certain accomplishment by taking advantage of the compulsions and restrictions obtainable only through the official legal powers of the State or Nation.

The quarantine field thus defined includes at times nursery inspection, tomato seed certification, and seed potato certification, as well as the more specific quarantine promulgations. All such projects have the common characteristic that in a greater or less degree the program makes use of special legal powers granted by either Congress or a State legislature. For this reason they assume a status somewhat different from that of the innumerable pest control efforts carried out voluntarily by the grower himself either on his own personal initiative or with valuable supplementary technical help and advice, an aid freely tendered but not of compulsory nature.

According to this viewpoint, quarantine and regulatory procedure cannot be regarded as an isolated undertaking, but simply as an additional means at the disposal of society in its constant and universal struggle against aggressive crop pests. It is available for use wherever it is obviously advantageous. It is most effective when it is combined and integrated with all the other measures devised to meet pest encroachment. In short, it constitutes another of the several elements in the general strategy of man versus pests, one more worth-while weapon against a common enemy. It thus fills a definitely useful place in the unity of human defense, along with all the other phases of the protective scheme.

RESEARCH RELATIONS

One of the most important relations of the regulatory field to plant pathology lies in the domain of research, since practically all successful attack on plant pathogens represents the translation of special scientific knowledge into field operations. Plant pathology is a relatively new science and regulatory efforts are a still more recent development. This means that the basic stockpile of scientific knowledge in this field is still far from complete. Not only is our fundamental accumulation scanty or lacking in many needed features, but also in its application a great many chinks and gaps remain to be filled in by supplemental investigation. All along the line there is urgent need for research.

Research is needed, in a fundamental sense, to bring into orderly perspective the still numerous unknown pathogens of the world; to establish clearly their host-ranges, climatic relations, life histories, and habits; their potentialities for crop damage; their means of dispersal; and the possibilities for their control. Basic research is thus as much a crying need for quarantine purposes as it is for ordinary control practices. It is gratifying to note the constantly increasing efforts now being devoted to broadening and perfecting the Nation's basic reservoir of knowledge on pathogens and their relations.

In addition to this slow and gradual increase in the general fund of available knowledge through patient research by innumerable students in a host of colleges and universities, experiment stations, industrial organizations, and governmental agencies, another type of research is needed in the quarantine field--special probelm research. When a new and destructive crop pest appears on the scene a special research program is nearly always needed to discover quickly certain essential facts about the newcomer. Without these missing details quarantine or regulatory measures cannot be intelligently planned; in their absence costly mistakes and failures are possible; and in any case until these critical points are clearly resolved, action is likely to fall below its highest efficiency. Because time presses for solution these research efforts take on

[1]While the writer has undertaken to assemble the information on the various subjects included in this review, he acknowledges with due gratitude the valuable assistance given by many colleagues in the Bureau of Entomology and Plant Quarantine and the Bureau of Plant Industry, Soils, and Agricultural Engineering, who have contributed most helpfully to its preparation.

the character of emergency projects. They have to be stripped to essentials--streamlined. The urgent time element also forces upon an administration all sorts of arrangements for the sake of expediency. Research units or individual workers are suddenly detached from less pressing problems and assigned to the new and urgent task; portions or phases of the problem are farmed out to centers where personnel and facilities exist, and funds must be secured from whatever sources are available.

In the domestic quarantine field most of the emergency research of this type in the plant pathological field has to be arranged with the Bureau of Plant Industry, Soils, and Agricultural Engineering or through State college and experiment station facilities. Research in disease problems cannot be undertaken directly by the quarantine administration, although in insect problems the existing Departmental organization permits a somewhat closer coordination between the quarantine and the research functions. In the early years of quarantine development considerable difficulty was encountered in providing for emergency research problems, largely because trained technical workers were not always available. With the greatly increased numbers of experienced plant pathologists now in State and Federal service, the possibility of arranging for prompt emergency research work is not nearly so difficult as it used to be.

A Division of Control Investigations has been set up in the Bureau of Entomology and Plant Quarantine to develop and perfect control procedures, largely in those phases of the regulatory field which can be solved in their mechanical, chemical, or operational aspects without extensive biological research.

A third and minor field of progress in knowledge concerns the numerous opportuntiies presented in the field operations of a quarantine or regulatory project for the study and improvement of important features of its own procedures. In the nature of things these needs must be recognized and evaluated by the workers themselves, and since they likewise possess the intimate knowledge necessary for planning and conducting studies on these difficulties, it seems natural that these project investigation problems should not be farmed out in other quarters, but should be solved as far as possible on the spot. The type of studies normally falling into this category would include investigations intended to improve inspection methods, to work out cheaper, simpler, or more effective treatments, to lighten restrictions, to simplify procedures, and in general to save time and effort in the interests of more economical operation.

DETERMINATION OF SPECIMENS

The Division of Domestic Plant Quarantines in its quarantine administration, its transit inspection activities, and its survey features is not well equipped to determine all hosts and plant pathogens encountered in its activities. Outside the foreign plant quarantine service, elsewhere discussed, the need for pathological identification facilities may arise in connection with (1) specific quarantines (white-pine blister rust, and black stem rust), (2) plant disease specimens obtained by the transit inspection service, (3) host and pathogen materials collected in various survey activities, (4) specimens needing technical determination in the course of enforcement of the Distirct of Columbia regulations, and (5) various host and pathogen materials coming to light in cooperative relations with the States (phony peach, peach mosaic, golden nematode, and potato rot nematode).

In general the need for technical help in identification is not very great in such problems as stem rust and white-pine blister rust where the host range is well established and the disease organism is easily recognized. Even here, however, outside help has been called in in such matters as the confusing pinon rust, the sorting out of ribes host species, and testing of barberry varieties to stem rust. In the identification of golden nematode survey collections and those of the potato rot nematode the Bureau has been altogether dependent on the Division of Nematology of the Bureau of Plant Industry, Soils, and Agricultural Engineering. Similarly, all specimens of abnormal citrus leaves encountered during the citrus canker survey have been submitted for bacteriological determination by the Bureau of Plant Industry, Soils, and Agricultural Engineering. Although the Bureau has now developed its own facilities and techniques for determination of the Dutch elm disease fungus, much help had to be obtained in the early days of this problem in sorting out this organism from others found in elm twigs.

Cooperation of this sort has been common all through the course of quarantine development. It began in the days of powdery scab and was prominent in the flag smut and take-all situations. In Woodgate rust and the bulb nematode quarantine, heavy reliance for accurate identification of specimens was placed on certain technical agencies in the Bureau of Plant Industry, Soils, and Agricultural Engineering and elsewhere. Uncertain or doubtful cases of peach mosaic in new areas are submitted as budwood for verification tests to the virus study centers of the same agency.

In this and other cases where an official determination is desired for legal reasons, it is standard practice to have critical disease specimens pronounced upon or confirmed by competent and recognized authorities outside the quarantine administration. In the same way disease specimens collected in the course of transit inspection, or in special survey programs, or in the extensive cooperative relations with the States cannot always be determined with finality within the quarantine administration, and must be referred for accurate disease diagnosis or pathogen identity to some recognized pathological or mycological expert.

It is gratifying to note that cooperation in these matters of determination has always been freely and generously contributed.

TEACHING

In general, plant pathology as taught in our colleges and universities normally includes a study of the nature and systematic relationships of disease organisms; their relations to their hosts in the matter of host range, crop damage, means of dispersal, seasonal adaptations, symptoms and their significance; and the various control or suppressive measures that may be employed to protect agriculture against these destructive intruders.

As explained above the quarantine and regulatory activities of State and national administrations constitute one element in the defense scheme of society against pest encroachment, and as such it merits a definite place in the stock of information and viewpoint presented for the instruction of a future generation of citizens. That this aspect of the pest control struggle has not yet become a routine item in all classroom instruction in plant pathology is due in part to the newness of its introduction on the scene, and perhaps in still greater degree to the absence of any comprehensive text book on the subject. The future will doubtless see this situation corrected so that an explanation of the part played by quarantines will be included as a normal feature in all courses of plant pathology.

Instruction on this phase of the subject on the college level should be an essential feature of a curriculum. The rapid recent developments in the quarantine field, the extent of operations now carried out in it, and the wide effects quarantine and regulatory measures may bring about in the lives and fortunes of innumerable citizens, all indicate the need for authentic college instruction and guidance to meet practical real life situations. Such teaching serves not only to disseminate helpful information to the vast body of the educated public, but it assures that the students of today who will be the agricultural leaders of tomorrow will be intelligently equipped to meet the problems that must inevitably arise for them in this field.

College teaching has another angle of interest to the regulatory field. Quarantine officials and inspectors, State and Federal, require a somewhat special training for their work, covering a group of subjects more or less overlapping into several of the normally accepted training courses. The teaching profession has an obligation to prepare students adequately for this type of service, perhaps, just as it attempts to provide training for other special branches of agriculture. At the present time several institutions have recognized this need and are endeavoring in various ways to fit some of their students for positions in regulatory work. Along with entomology, plant pathology would constitute a major subject in this scheme.

Below college level, high school and to some extent public school, curricula will probably come gradually to include something in skeleton form on the aims and methods of quarantine and regulatory projects, either by way of explanation of current local problems, or as a part of the general fund of knowledge indispensable to every citizen.

THE EXTENSION SERVICE

The Extension Service is an exceedingly important organization for quarantine and regulatory success. It is in fact a two-way channel--on the one hand collecting facts and figures useful and at times invaluable to the regulatory service, and on the other serving as effective dispenser of information, stimulator of community enterprise, and the molder of correct public sentiment. The County Agent or extension representative can do more to make or break a regulatory project locally than almost any other individual.

In line with the conception that a quarantine undertaking must have wide public approval and support to be permanently successful, State and Federal administrations alike are coming more and more to recognize the helpful role of the Extension Service in spreading dependable knowledge on local quarantine affairs, correcting erroneous impressions and encouraging a spirit of healthy cooperation among growers, business interests, and the public generally.

PLANNING

If we look upon a quarantine project, not as a mere bureaucratic function, but as a community undertaking, it is apparent that it should have the approval and support of a wide sector of at least the responsible and influential public. Without this general backing the chances for success are small. Because of this dependence on public support, it is an accepted policy in planning any important quarantine enterprise to consult with various critically placed groups or with their leadership so as to assure for the project beforehand a favorable public support. In other words, planning as well as carrying out must take into account the interested public.

Certain distinctions are needed here, however. While the general public can grasp readily and shrewdly matters of crop damage, project cost and economic benefit, and can decide wisely on the worth of a proposed program from this familiar viewpoint, it cannot be expected to understand the often complex relations in the biological field on which quarantine action must be based. Fortunately complete and detailed understanding in this difficult phase of planning is not necessary. The public places a vast faith in the integrity of the nation's scientific workers and is well content to trust their expert judgment in these intricate matters. Fortunately again, there are a number of sources independent of either State or Federal quarantine administration which can be called on to contribute to the planning process the special knowledge, wide experience, and sound viewpoint gained in personal studies and investigations in the technical phases of pest control. The help thus available in the formulation of quarantine plans from these specially trained and equipped scientists constitutes an invaluable element in setting up action programs.

Plant pathologists, either individually or through their organizations, are in a position to contribute materially toward the proper use and development of the quarantine method by their counsel and guidance. Whether this participation represents an official job responsibility, or arises out of personal interest in a technical subject affected by some quarantine, or concerns only group discussions leading to sound conclusions and opinions, or whatever the approach, it is surely the duty of the plant pathologist in his role of public service to help adjust this additional means of pest control correctly and effectively into the national scheme.

The history of past quarantine projects in the plant disease field brings out clearly the numerous and constructive contributions made by pathologists from the beginning in the planning process. Their intimate knowledge and special experience have helped to mold and direct quarantine action all along the way. Their opinions and viewpoints have been important factors in imposing, modifying, or revoking many quarantine and regulatory measures, and their criticisms and suggestions have tended to keep quarantine regulations, methods, and procedures on a more effective and practical basis. The helpful interest of many keen and well-informed pathologists outside the quarantine administration has profoundly influenced the course of such projects as powdery scab, Woodgate rust, white-pine blister rust, chestnut blight, and the Dutch elm disease. That same interest is currently active in such problems as the citrus canker survey, black stem rust, the golden nematode problem, and the peach virus diseases. Similarly, pathologists have effectively exercised a helpful role in the field of disease survey methods, the improvement of inspection methods, the development of new and more effective treatments, and in the discovery of new facts and relations. All such contributions aid materially, directly or indirectly, in the formulation of quarantine plans; they may promote greater effectiveness, lead to a more practical program, or reduce costs.

In addition to this general assistance given by pathologists to the planning of quarantine efforts, mention should be made of the valuable contribution to quarantine planning made by the National Plant Board and its subsidiary bodies, the four regional plant boards. These organizations are made up of representatives from the quarantine and regulatory services of all States, but function on a purely advisory basis. Because of their familiarity with State quarantine problems, these groups are peculiarly fitted to understand and assess the worth of all quarantine proposals, State or Federal. They thus constitute a competent board of experts and their viewpoints and opinions carry tremendous weight in quarantine planning. It is noted, however, that a large majority of board members are primarily entomologists, and for this reason plant board interest is substantially greater in insect matters than in plant disease problems.

To some extent this unbalance is compensated for by an arrangement made in 1944 with the American Phytopathological Society, whereby a permanent committee appointed by that organization has been assigned to confer on disease problems arising in the quarantine field with the Bureau of Entomology and Plant Quarantine, and after studying these to report to the Bureau its analysis and recommendations. It may be expected that this committee will not only benefit the quarantine administration by its deep technical insight into the pathological aspects of the situations reviewed, but will also serve as a channel to bring back to the Society a clearer understanding of quarantine aims and viewpoints.

Outside the plant quarantine administration but still within the Department of Agriculture itself are to be found a number of pathologists who can be called upon to help in the quarantine planning process, particularly by presenting and evaluating all the known facts and relations available to each of these specialists in his own special field of study. The administration relies heavily on this source of help, and regards these contributions as of special official weight.

THE TRANSIT INSPECTION SYSTEM

Transit inspection was begun in 1920 (46) to assist in the enforcement of the white-pine blister rust quarantine which prohibited the movement of white pine and ribes nursery stock from the infected eastern areas across the plains into the then still rust-free regions of the Pacific area. Arrangements were made at that time to place inspectors at strategic midwest traffic centers and transfer points so that freight, express, and parcel post shipments could be checked on their way to the West. This type of inspection was found so effective that the service was set up as a specific project on July 1, 1930, and expanded to provide the same type of assistance in enforcement of other Federal domestic quarantines and to furnish reports to State inspection officials of shipments observed to be moving in these channels in apparent violation of State plant quarantines or nursery inspection requirements. Assistance is also given to the foreign plant quarantine service by calling attention to foreign shipments of plants and plant products found to be moving in violation of foreign plant quarantine regulations. It is to be understood that transit inspectors are empowered to take appropriate protective action in the case of infractions of Federal domestic quarantines, but merely report upon infringements of State quarantines or of violations in the foreign plant quarantine field.

Transit inspection is now operating, either throughout the year or seasonally at 16 major freight, express, and parcel post distribution and transfer centers, and keeps under scrutiny traffic movements in all directions through such bottlenecks as an aid in the enforcement of the eight Federal domestic plant quarantines. Of these, the quarantines on account of white-pine blister rust and black stem rust are of particular interest to plant pathologists.

It should be added that several States assign inspectors to cooperate in transit inspection on a full or part-time basis.

At first glance it might seem impossible for a limited number of inspectors to cover effectively the tremendous mass of commodities pouring through the traffic channels of our vast network of public carriers. Yet from much study, planning, and experience in the development and application of methods of selective examination, helpful cooperative relations with common carriers, and arrangements with postal officials, an unexpectedly large coverage has been attained of shipments of quarantine interest in the moving streams of plants and plant products. Further, through the reporting and investigation of apparent violations and the distribution of helpful information on procedures, the transit inspection service is able to keep the public on a far higher plane of compliance with regulations than could be obtained at equal cost in any other way.

FEDERAL DOMESTIC PLANT QUARANTINES

Domestic plant quarantines represent Federal efforts to prevent the interstate spread of injurious pests by the exercise of control over interstate commerce. The States relinquished this control to the Federal government and it was made operative by the Plant Quarantine Act of August 20, 1912. Section 8 of this Act gives the Secretary of Agriculture power to place a State or group of States under quarantine on account of a specified injurious agricultural pest; to prohibit or regulate the interstate movement therefrom of plants, plant products, and other materials likely to disseminate the pest; and to make such prohibitions or regulations applicable to the whole State or to a specified portion thereof. It is important to note that this grant of power may be exercised only over such articles or materials while they are moving from one State to another in interstate commerce. Control over movements wholly within the State itself (intrastate movement) comes under the State's own powers.

Because the Federal power is thus definitely limited, many pest situations involving complex quarantine action require a combination of both State and Federal quarantines to obtain effective results. In addition to this possibility of concerted quarantine action by both State and Federal agencies, a further provision of Section 8 of the Plant Quarantine Act authorizes the Federal authority to cooperate with the State in the enforcement of State quarantines. Liberally construed, this cooperative provision permits Federal assistance to be given in many ways to State-planned quarantine projects, whether a Federal quarantine is in effect on the subject, or whether only a State quarantine has been promulgated.

During the period from the passage of the Plant Quarantine Act (August 20, 1912) to the end of 1949 there have been promulgated ten Federal domestic interstate quarantines on plant disease subjects. For reasons of administrative expediency two of these (No. 15, on sugarcane from Hawaii and Puerto Rico, and No. 60, on sand, soil, or earth from Hawaii and Puerto Rico) are administered by Foreign Plant Quarantine personnel and are, therefore, included in that Division's list. Six of the remaining eight have been revoked, thus leaving in effect at the present time only two of these measures--black stem rust, No. 38; and white-pine blister rust, No. 63.

Miscellaneous Disease Problems

In addition to these eight specific problems a great many other disease situations have from time to time come up for quarantine consideration, but for various reasons have been set aside as not requiring Federal quarantine action. An incomplete but typical list of these would include the following:

Quick decline of citrus (virus)
Internal cork of sweetpotatoes (virus)
Several prunus virus diseases such as the "X" disease, peach yellows, peach rosette, cherry buckskin, cherry dwarf, peach wart, etc.
Rose mosaic (*Marmor rosae*)
Sugarcane mosaic (*Marmor sacchari*)
Phloem necrosis of elm (virus)
Narcissus mosaic (virus)
Walnut brooming disease (virus)
Potato rot nematode (*Ditylenchus destructor*)
Root knot nematode (*Heterodera marioni*) (= *Meloidogyne* spp.)
Potato bacterial ring rot (*Phytomonas sepedonica*) (= *Corynebacterium sepedonicum*)
Poplar canker (*Dothichiza populea*)
Willow scab (*Physalospora miyabeana*)
Oak wilt (*Chalara quercina*)
Mimosa wilt (*Fusarium oxysporum* f. *perniciosum*)
Filbert blight (*Cryptosporella anomala*)
Azalea flower blight (*Ovulinia azaleae*)
Camellia flower blight (*Sclerotinia camelliae*)
Ozonium root rot (*Ozonium* (*Phymatotrichum*) *omnivorum*)

Federal quarantine power has not been invoked for these and numerous other similar plant disease situations for any one of a variety of reasons or combinations of these.

1. The disease may be too unimportant nationally to justify expensive quarantine effort or trade disturbance; costs would be out of proportion to the benefits to be expected.
2. Quarantine usefulness is questionable because of a still unknown pest distribution, or lack of knowledge on key features, or the recognized inadequacy of available measures in preventing spread, or the existence of important uncontrollable means of spread.
3. Reasonably successful means of control are available, which may largely obviate the need of Federal quarantine measures.
4. Certain problems can be solved more effectively by State than by Federal quarantine action.
5. The Federal agency by virtue of well-planned cooperation with the States in their quarantines or other regulatory measures can often fulfill its responsibilities without imposing an official Federal quarantine.
6. The level of national support may be inadequate as indicated by popular apathy, adverse influential sentiment, undeveloped technical opinion, the clash of conflicting interests, or in the matter of minimum necessary appropriations.

The eight plant-disease problems which at one time or another have engaged Federal attention so deeply as to have resulted in domestic quarantine promulgation are here reviewed to bring out their chief relations to the field of plant pathology.

The Bulb Nematode

The bulb and stem nematode *Ditylenchus dipsaci* has long been known on numerous hosts other than bulbs. Its frequent occurrence to a damaging extent in clover and alfalfa fields in the

Pacific States was the basis for a quarantine hearing on October 2, 1923,[2] but the evidence there brought out indicated that this nematode was already widely distributed on these hosts. The injuries to alfalfa and clover in the Western States were dependent, it was thought, on locally favorable climatic conditions, and the quarantine proposal was dropped.

In 1926 increasing reports of bulb nematode infestation in domestic narcissus bulbs led to its inclusion in the narcissus bulb Quarantine No. 62, effective July 15, 1926,[3] as a reason for promulgating this measure along with the greater bulb fly (Merodon equestris Fab.) and the lesser bulb fly (Eumerus strigatus Fallen). This quarantine aimed to establish Federal regulatory control over all interstate movements of narcissus, with the object of reducing or suppressing these three bulb pests in the country's bulb-producing areas. The plan provided for a field and a harvest inspection, treatment by fumigation or hot water methods for infested lots, and certification for interstate movement. Additional regulatory procedures to be carried out by State authority governed the culture and production of narcissus.

A report on the inspection and certification operations of this quarantine for a single typical year, 1929, in 29 States and the District of Columbia listed almost 175 million bulbs of Polyanthus type examined and nearly 100 million of the Daffodil type, and over 160 million bulbs of both types were certified, and over 50 million daffodil bulbs had to be treated.[4]

Quarantine No. 62 together with its regulations was revoked, effective April 1, 1935[5]; the lesser bulb fly had already been dropped from the quarantine June 20, 1932. The reasons given for revocation were that both bulb nematode and greater bulb fly incidence had steadily increased so that the expected general suppression had not been realized. Contributing to this disappointing result was the fact that both pests were becoming more widely spread; that the bulb eelworm was now known from over 50 hosts, many of them native plants; and that the nematode was present in and presumably being carried about by other bulbs not covered by the quarantine. The effectiveness of the hot-water treatment against the bulb nematode had likewise been called into question. Under these circumstances it seemed best to withdraw the Federal quarantine and leave both cultural control as well as the certification for interstate shipment in the hands of the individual States, with such assistance by the Federal agencies as could be furnished in special problems. This arrangement is still in effect.

Considering only the nematode aspect of this quarantine as of primary interest to the plant pathologist, it is clear that neither distribution nor host relations were sufficiently well known at the outset. We may perhaps interpret much of the later reported increase in distribution as representing merely late discoveries rather than actual spread. Again, the complex host relations that later came to light provided another example of the unfortunate necessity of making quarantine decisions before adequate information was available. Finally, the doubt cast later on the efficacy of the hot-water treatment traces back to technical sources rather than to faulty quarantine judgment.

It is easy to attribute the lack of success and the final abandonment of this quarantine effort to imperfect official planning. It should be recognized, however, that the control scheme attempted was a legitimate conception hopefully designed to serve the national interest. Its weakness lay in the lack at the outset of adequate knowledge of host range, distribution, and control methods. Thus, lag in the technical field was an important element in the unsatisfactory outcome of this effort. This viewpoint attaches no blame to the technical agencies concerned; for various reasons they were unable to contribute immediately all the data needed for sure quarantine judgment. The situation merely emphasizes that intimate interrelation must prevail between the quarantine function and other phases of plant pathology, and that close teamwork is important in providing a sound basis for quarantine action.

Black Stem Rust

The black stem rust of cereals (Puccinia graminis) as a pathogenic species is generally present in the United States and has been here since early colonial days; further, it is readily spread by wind. Because of these relations, quarantine would seem to be useless, and only control measures could be considered.

Yet quarantine action has a definite place in the stem rust situation, because of the important role of the alternate hosts (Berberis, Mahonia, and Mahoberberis) in starting early local infec-

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[2]S.R.A. (U.S. Bur. Entom. & Plant Quar. Service & Regulatory Announcement) 1923, p. 118.
[3]S.R.A. 1926, p. 70.
[4]S.R.A. 1930, p. 48.
[5]S.R.A. 1935, p. 10.

tions and in serving as a breeding ground for new and more virulent stem rust races. Because of these highly dangerous characteristics, rust-susceptible members of the barberry group have been sentenced to extermination in the important grain-producing areas of the country. It is only in this special feature of barberry eradication that the quarantine powers of both Nation and State have been called upon.

Quarantine effort aims to prevent the movement of rust-susceptible barberry and mahonia into grain-growing areas, and to prevent replanting of these undesirable rust hosts in areas already cleared from them.

The campaign to eliminate these dangerous hosts from the scene involves: 1 -- the destruction of rust-susceptible barberry and mahonia plants throughout the areas producing wheat and other cereals attacked by stem rust; 2 -- maintaining these areas free from these alternate hosts on a permanent basis; 3 -- restriction of all barberry and mahonia planting throughout the protected areas to species and varieties determined to be rust-resistant; 4 -- the testing of these varieties to establish their rust resistance or susceptibility; 5 -- supervision of nurseries growing barberry and mahonia plants for sale and distribution and the certification of their rust-resistant species and varieties for movement; 6 -- prohibition of movement into the eradication States of barberry seeds, which because of ready hybridization are likely to produce rust-susceptible plants; and 7 -- transit inspection at key points and traffic bottlenecks to assure that the restrictions and requirements on seeds and plants of barberry, mahonia, and mahoberberis are being observed.

Federal Domestic Plant Quarantine No. 38 was issued, effective May 1, 1919[6]. It prohibited shipment into certain States where barberry removal was in progress of plants of 31 named species of barberry and three of mahonia. A widespread voluntary cooperation of nurserymen was arranged to assure against distribution of the susceptible plants.

The quarantine was revised several times to take care of problems as they arose. Mahonia repens was removed from the list of susceptible plants; unrooted mahonia cuttings were allowed to move without restriction for decorative purposes, and additional States were included in the protected list.

The most recent revision of May 1, 1949, designated through administrative instructions 39 species and varieties of barberry, mahonia, and mahoberberis, regarded as rust-resistant and thus eligible for interstate movement under permit; the regulatory control over host movement was extended to all areas of the continental United States; and a prohibition was placed on the movement of fruits and seeds into the eradication States unless these could be shown to have come from resistant plants in which case movement under permit was allowed.

As above indicated, quarantine activity constitutes but a subsidiary element in the black stem rust control program, the chief feature of which has been the elimination of the susceptible alternate hosts from extensive grain-growing areas. The technical knowledge and experience basic to this ambitious undertaking takes its rise far back in European history. According to Fulling (15) observations in Rouen, France, and elsewhere in Europe in the 17th century linked wheat "blast" to the barberry; early in the 19th century barberry suppression was being carried out in Germany by legal orders; France, Denmark, and Austria, likewise, enacted such laws; Connecticut, Massachusetts, and Rhode Island attempted barberry eradication to protect wheat in the 19th century also; North Dakota in 1917, and Iowa, Montana, Nebraska, Minnesota, Michigan, South Dakota, and Wisconsin recognized the role of barberry in perpetuating rust in 1919 and banned these shrubs by law; Wyoming came into the list in 1921 and Oregon in 1923.

State efforts to suppress susceptible barberries were more or less unified by the eradication effort established in 1918 by the U. S. Department of Agriculture which attempted to inaugurate a common program in 13 wheat-growing States--Colorado, Illinois, Indiana, Iowa, Michigan, Minnesota, Montana, Nebraska, North Dakota, Ohio, South Dakota, Wisconsin, and Wyoming. Later, other States joined in the control program. A similar movement was begun in 1917 in Canada which later included the provinces of Ontario, Manitoba, and Saskatchewan. It was to strengthen this extensive protective campaign that Federal legal powers were brought into the scene in 1919 in the form of Quarantine No. 38.

Pathological contributions to this stem rust problem have been numerous and varied. Only those of key significance in the quarantine phases of the problem can be referred to here. Outstanding of course is the proof by De Bary in 1865 (14) of the specific unity of the aecial barberry stage of the rust with that on wheat. This brilliant work vindicated the conclusions long before reached by observant growers, and placed control measures on a sound technical basis.

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[6] S.R.A. 1919, p. 58.

Two other contributions have been fundamentally important in the quarantine sense. One of these demonstrated the sexual process taking place during the barberry stage and gave convincing assurance that different rust strains may thus meet, cross, and produce new races on the barberry (11). The other embraces the results of long-continued and careful studies by many pathologists on the characters, areal range, and host relations of over 200 distinct races of wheat rust (51, 52). These race studies in stem rust have been so extensive and of such far-reaching significance that they may be said to have established a new viewpoint in quarantine philosophy--the necessity of taking into account these individual and varying strains as pathogenic units instead of regarding the species as the sole and final unity.

That the quarantine measures depended on to strengthen the general stem rust control campaign have well served their purpose of preventing the continued planting of susceptible alternate host species and varieties in the protected States may be attributed to several factors. In the first place the needed quarantine steps were of simple and obvious type; second, restrictive action both at the outset and in its subsequent developments has been soundly grounded on well-established biological relations; third, the quarantine procedures adopted have had the general approval and support of plant pathologists everywhere; fourth, the nursery industry has from the beginning cooperated most effectively in complying with the planned procedure. Finally, the national importance of the wheat crop, its tremendous value, and its wide culture have all served to create strong public support for the stem rust campaign including its accessory quarantine feature.

Chestnut Blight

The chestnut blight or canker fungus (Endothia parasitica) was probably brought from Asia in chestnut nursery plant importations some years prior to its recognition as a definite chestnut parasite by Murrill in 1906 (41). In contrast with the situations in potato wart, white-pine blister rust, and the Dutch elm disease where foreign behavior gave advance notice of destructive possibilities, the chestnut blight fungus was unknown as a serious pathogen until it came into contact with the very susceptible American chestnut (Castanea dentata). At the time of its discovery it probably had been spread generally by nursery stock distribution and spore dispersal. By 1908, it was reported to be widely distributed in the Hudson River Valley and in the vicinity of New York City.[7]

In the years prior to the Plant Quarantine Act of 1912, control or suppressive measures were possible only through State legal powers supplemented by Federal technical assistance. Typical of such efforts was the work of the Pennsylvania Chestnut Blight Commission instituted early in 1912 (45) to bring all available State resources to bear on the blight problem. These early efforts were somewhat confused by the occurrence of other similar fungi on the chestnut and by failure in some quarters to recognize promptly the seriously parasitic character of the new intruder (10). The discovery of the fungus in Asia in 1913 helped to clear up these early difficulties (18, 48).

A Federal domestic quarantine was brought up for consideration at a hearing on May 18, 1915.[8] At that time the blight was known to be present all through New England, New York, the middle Atlantic States of New Jersey, Pennsylvania, Delaware, Maryland, Virginia, and West Virginia, and cases had been reported from North Carolina, Ohio, Iowa, and Nebraska. The impossibility of preventing further natural spread in the East by quarantine measures was now recognized, and it was indicated that State quarantines to prevent diseased nursery stock distribution were preferable to Federal action. This attitude has continued until the present; several Western State quarantines of protective type are still in effect.

At the beginning of the blight campaign there was intense activity in every line that held hope of suppression, control, or delay in spread. Spraying methods, chemical treatments, pruning operations, and isolation procedures all failed to bring appreciable results (38). Although it was soon apparent that the gradual onward march of blight could not be prevented, a system of patrol to suppress foci of infestation far in advance of the main body was instituted, and this step appears to have rendered valuable service in appreciably delaying blight progress and thus giving an opportunity for the orderly salvage of large quantities of stricken chestnuts for timber or lumber use.

From the outset emphasis has been placed on a search for blight-resistant chestnuts (18). Search was made in our native chestnut stands for individual trees or healthy tiller shoots which

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[7]S.R.A. 1915, p. 25.
[8]S.R.A. 1915, p. 25.

had survived the general destruction, and might thus possess resistant characters rather than merely represent accidental escape. No outstanding results have been obtained from this search. Attempts have also been made to incorporate resistance in acceptable hybrids by crossing the American species with commercially useful resistant Asiatic chestnuts, a necessarily slow and tedious process. While this line of attack, persistently carried out by the Bureau of Plant Industry, Soils, and Agricultural Engineering, has produced promising results, there is as yet no blight-resistant cross that can match the native species in all the desirable features of timber character, nut quality, seed reproduction habit, and tillering ability. A third line of effort is underway to search out the best types of Asiatic chestnut having inherent resistance to blight, and to distribute seeds of these for planting in forests as a substitute for the vanishing native species (19). Considerable progress is being made in this direction, and this movement is likely to gather impetus with the years.

As was predicted, all efforts to stop or materially delay the progress of chestnut blight have failed, and the fungus has swept southward and westward practically unchecked through the eastern chestnut stands. It has now reached almost to the southern limits of the chestnut in the Appalachians, and has been found as well in isolated spots in the far West and British Columbia.

From the quarantine point of view the lack of success in preventing spread in the eastern chestnut range can be attributed neither to early misunderstandings on the relations and potentialities of the blight fungus (9), nor to inability to marshal sufficient funds and manpower to fight the intruder. Quarantine effort is most effectual in connection with the controllable movement of pest-carrying materials, and here found itself relatively helpless against natural wind transport or bird and animal dispersal of the tremendous spore population produced by an aggressive parasite on an extremely susceptible and plentiful host. Undoubtedly, the State restrictions imposed on nursery stock movement were of considerable value, since their delaying action gave time for an orderly utilization of tremendous quantities of the dead and dying wood and timber products. In spite of this slowing down, however, the pest swept inexorably on its destructive way. Even the drastic measure of complete host suppression in the originally infected area, so as to eliminate this inoculum at the source, could scarcely have been expected to succeed, partly because of the extensive distribution of blight when its true nature was first recognized, but still more because of the host's unusual capacity for tillering. The fungus could perpetuate itself on the succession of shoots for many years.

In this eastern campaign the chestnut blight fungus is likely to remain for long a classic example of extremes in the quarantine sense--mild behavior in its native home, unusual virulence on its new American host, uncontrollable natural dispersion by wind, failure of conventional control methods, and only partial success as yet in the one hopeful feature of developing resistant chestnut types.

In the Pacific region where the chestnut is not indigenous the struggle against blight has been more successful. Scattered plantings of American, European, and Asiatic chestnuts have been made in the three coast States and in British Columbia, Canada, and blight centers have been located in all of them (20). However, eradication measures have been successful in Washington and Oregon, and the repressive measures taken in the few infected California plantings seem to be preventing further spread (1).

Citrus Canker

A review of the long and remarkably successful campaign against citrus canker (*Bacterium citri* (Hasse) Doidge) (= *Xanthomonas citri* (Hasse) Dowson) will appear in a forthcoming *Supplement* of the *Plant Disease Reporter*. This story covers developments from the finding of the organism in 1913 to the recent and entirely negative survey operations carried out in Texas and Louisiana, 1947-49. Activities through this period in the seven Southern States concerned included intensive and repeated survey, on-the-spot destruction by fire of all infected trees, the meticulous supervision of citrus nurseries and their environs, and the eradication of countless wild, escaped, and abandoned citrus trees (17). This energetic and sustained eradication effort was begun by the southeastern citrus States as soon as the destructive character of the disease was recognized (3). The program set up in these States was strengthened and supported by the Federal government through the Bureau of Plant Industry from 1915 onward to 1935 and continued thereafter by the Bureau of Entomology and Plant Quarantine.

The complete elimination of a bacterial disease of virulent and contagious character from widely scattered centers in seven States would seem to be an almost hopeless undertaking. That its suppression was accomplished not only effectively but rapidly throughout this wide area was

not only due to the deep and sustained interest of the Federal agencies, but still more to prompt and energetic measures taken by the States themselves, and also to the outstanding assistance and support accorded by citrus growers, nursery firms, and the public generally. Few programs of regulatory nature have commanded such complete cooperation among the various elements concerned as this canker problem. It was truly a community undertaking.

Largely because of the prompt and determined action taken at the outset encouraging results were soon obtained (34). Florida had largely suppressed its numerous canker spots by 1916; the State continued its drastic measures for its few recurrent cases until 1927, since which date no canker has been known there. South Carolina saw the end of its canker in 1916, and Georgia in 1917; in Mississippi the last traces were noted in 1922; and Alabama has been canker-free since 1927. The disease held out for some years in Louisiana where nurseries and commercial citrus plantings were pronounced free from canker in 1940; and in Texas where no canker has been seen in the nurseries or commercial orchard citrus since 1941. The last known Texas record of citrus canker was a single leaf of a small escaped seedling found in 1943.

The cooperative Federal-State search for canker continued in Texas until 1944 and then after two inactive years was resumed in 1947 to 1949 in Texas and in Louisiana in 1949. At the end of 1949 no case of canker has turned up in either State, and the evidence from these extensive and thorough survey efforts seems to justify a confident hope that this virulent citrus pest has been completely exterminated from the whole United States mainland.

Foreign Quarantine No. 19, effective January 1, 1915,[9] has been maintained since to exclude rigidly all foreign propagating materials likely to carry the canker organism, and this was supplemented by Foreign Quarantine No. 28, effective August 1, 1917, excluding citrus fruits susceptible to canker infection.[10] No Federal domestic quarantine to prevent interstate spread of canker has been imposed. Reliance was placed on the quarantine and regulatory measures set up by the several affected States, which, though largely intended for suppression purposes within the States themselves, were deemed adequate to deal also with problems of interstate spread, especially when supplemented by exclusion action taken by the relatively few citrus-producing States. These quarantine arrangements have appeared to work well; there has been no record of interstate spread of citrus canker in nursery stock channels through the years of quarantine operations.

At the outset Federal activities in the eradication of citrus canker were centered in the Bureau of Plant Industry, and this leadership was continued until 1935 when, in accordance with a general reallocation of Department functions, this project, along with several other disease control features, was taken over by the Bureau of Entomology and Plant Quarantine. Since that date it has been a responsibility of the Division of Domestic Plant Quarantines to bring to its present apparently successful state the eradication operations so energetically initiated and so largely accomplished in the early years by State and Federal cooperation.

For such an outstanding disease the relations to plant pathology have been comparatively simple. The establishment of the bacterial nature of citrus canker and the isolation and classification of the organism involved (24) provided a sound basis for control procedures. Methods of spread and the extremely contagious character of the malady (4, 57) were early known from field observations or were readily deducible from these. Questions of longevity in leaves and in soil (16) had to be answered, however, as well as the relation of the organism to fruit and containers (33). The destruction of infected trees in situ by fire was a grower contribution, adopted after ordinary spraying, pruning, and other similar practices had failed to check the spread. Throughout the whole campaign, however, it has been necessary to have doubtful or critical specimens identified or confirmed by expert bacteriological procedures, since field observation cannot be confidently relied on for canker determination. This service has been effectively rendered over the years by the Bureau of Plant Industry, Soils, and Agricultural Engineering.

The Dutch Elm Disease

The Dutch elm disease (*Ceratostomella ulmi* (Schwarz) Buisman) was first found in the United States in 1930 at Cleveland and Cincinnati, Ohio. Three years later it was found to be well established in parts of Connecticut, New Jersey, and New York around the Port of New York. In 1933 and 1934, diseased trees were found at Baltimore, Maryland; Norfolk, Virginia; and Indianapolis, Indiana. Concurrently, elm burl logs from Europe carrying *C. ulmi* and bark beetle vectors of the disease, were found entering the ports of New York, Baltimore, and Norfolk. A search of import records revealed that since 1926 about 500 elm burl logs had entered at these

[9]S.R.A. 1914, p. 89. [10]S.R.A. 1917, p. 104.

ports and at New Orleans, Louisiana. They had been shipped through and into 21 eastern, southern, and midwestern States over 13,000 miles of railroad. Subsequently, disease centers were found at Brunswick and Cumberland, Maryland; Athens and Ravenna, Ohio; Binghamton, New York; Wilkes-Barre, Pennsylvania; and Old Lyme, Connecticut. All but the last two locations are along railroads known to have hauled imported elm burl logs. In 1948, Dutch elm diseased trees were found in Denver, Colorado, but no clue as to how the disease reached there has developed.

All elm species occurring naturally in the United States are susceptible to the Dutch elm disease. They occur somewhat continuously east of the Great Plains and are planted extensively in all parts of the country. Asiatic elms are somewhat resistant to the disease. A few selected American elms and hybrids have shown disease resistance. A selected strain (Christine Buisman) of a European elm is highly resistant. There is no established method of making an elm immune from infection or of curing a diseased elm.

The Dutch elm disease is spread chiefly by two species of bark beetles. Hylurgopinus rufipes is a native insect and probably occurs throughout the natural range of elms. Scolytus multistriatus became established in the Boston and New York areas apparently soon after 1900, and subsequently in the Hudson, Susquehanna, Potomac, Ohio, and Mississippi River Valleys, and at Rochester, New York, and Denver, Colorado. The disease may be kept in check by destroying bark beetle sources and by spraying healthy elms with DDT to prevent their inoculation by these fungus-carrying insects.

During the 1930's an attempt was made to control and eradicate the Dutch elm disease in the United States by finding and destroying diseased elms and bark beetle sources in the known infected areas. Foreign Quarantine No. 70, effective October 21, 1933,[11] placed an embargo against imported elm materials which may carry the Dutch elm disease fungus and bark beetle carriers. Domestic Quarantine No. 71 was established, effective February 25, 1935,[12] to prevent the movement of hazardous materials from infected areas in Connecticut, New Jersey, New York, and Pennsylvania. The quarantine did not prevent persistent local spread of the disease by bark beetles, but the control effort probably reduced the rate of spread materially. When large scale control work was terminated in the early 1940's, the domestic quarantine was revoked, effective May 1, 1947.[13]

Various factors were concerned in the revocation of Domestic Quarantine No. 71. Both experience and expanding knowledge indicated that control was essentially a local problem and was thus predominantly a State responsibility. While interstate movement of nursery stock could be controlled by regulatory action, this was a relatively minor element in spread, and such movement could be restrained quite well by established State nursery stock inspection methods. Quarantine methods could not hope to prevent natural dispersal of the insect carriers, and were largely ineffective in controlling local, erratic movements of elm wood products in which both the fungus and carrier could possibly be disseminated. There were survey difficulties. Survey costs were high, and although identification in suspected trees could be made with sureness, evidence indicated that both fungus-infected wood and spore-bearing insect carriers were likely to exist in the areas outside of known infestations where tree symptoms had not developed. These relations not only brought uncertainty into the basic quarantine survey problem but debarred a confident prediction for final success of the program. This uncertainty was increased when further survey showed the insect carriers to be distributed more widely than at first was suspected.

In the field of popular support this uncertain outlook was a discouraging element. The modest reputation of the native elm as a timber tree also kept enthusiasm lukewarm in many rural areas; and while shade elms in towns were highly valued, their enforced removal sometimes stirred resentment and frequently imposed heavy costs on property owners and municipal finances. On the whole, therefore, public interest and approval never did attain the strength and momentum necessary for the success of such a widespread and costly undertaking.

With the revocation of Quarantine No. 71 problems of control, as well as prevention of spread now center in individual States, and several western States have since then promulgated interstate quarantines to protect themselves against Dutch elm disease introduction from eastern sources. Federal interest in the problem is still maintained and the Bureau of Entomology and Plant Quarantine maintains a laboratory for making conclusive identifications of the Dutch elm disease organism, thus distinguishing it from other vascular pathogens causing somewhat similar symptoms. The Bureau and a few State agencies are engaged in testing bark beetle control

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[11] S.R.A. 1933, p. 245. [12] S.R.A. 1935, p. 4. [13] S.R.A. 167; 1947, p. 4.

measures which may be effective and practical for elm owners city foresters, and arborists. Sanitation measures and spraying with DDT are receiving close attention. State and commercial pathologists are investigating therapeutic materials and techniques for controlling the Dutch elm disease. Federal and State pathologists are continuing efforts to find and make available resistant elms which will be suitable for home, park, and street planting.

Several American pathologists have contributed materially to what is known about the Dutch elm disease. For many years L. M. Fenner handled the large volume of identification work and developed special techniques for large volume culturing. W. Banfield, A E. Dimond, and A. Feldman have contributed much on pathological processes, and, in addition, the last two have developed chemotherapy techniques. W. H. Rankin, M. A. McKenzie, H. V. Wester, and E. G. Rex have devoted much time to control programs and methods. Curtis May, D. S. Welch, Roger Swingle, and J. M. Walter have led in the development of resistant strains. O. N. Liming has been directly connected with all phases of the control program since its inception in 1930.

Flag Smut

Action was taken by Foreign Plant Quarantine No. 39, effective August 15, 1919, to shut out from certain specified countries seed or paddy rice, on account of two diseases--flag smut (Urocystis tritici) and takeall (Ophiobolus graminis)--as well as to regulate the entry of wheat, oats, barley, and rye from those specified countries. Concurrently with the hearing which preceded promulgation of this quarantine and on the same date, July 15, 1919, a similar hearing was held[14] to discuss the need for a domestic quarantine on the same two diseases and on the wheat nematode (Tylenchus (Anguina) tritici). Flag smut had been found in Illinois where it was thought to have become established through a wheat shipment from Australia brought in as an emergency measure during World War I. The takeall disease was known to be present in Illinois and Indiana, and the wheat nematode was reported to occur in Virginia, West Virginia, and Georgia. It was proposed to consider quarantine restrictions on the interstate movement from these several States of wheat, oats, rye, spelt, and emmer.

However, the hearing developed much information and viewpoints which materially affected the proposed action. The eelworm disease, it was brought out, had been long present in the country, and though probably widely distributed outside the three States mentioned, had not shown any pronounced tendency to spread, and could be controlled with reasonable effort by the States concerned. It was forthwith dropped from the quarantine consideration.

In the case of takeall, the fact that the fungus concerned was unlikely to be carried to any extent on seed rendered quarantine control over seed or grain practically useless. Moreover, local control was also possible and there was grave doubt that the fungus was restricted to the two locations then known to be infected.

The flag smut outbreak was considered more threatening. The fungus was definitely known to be seed-borne and had a bad record in Australia and other wheat areas of the world. Yet the area affected in Illinois was small; considerable hasty survey had failed to uncover other infection centers; Illinois was taking effective steps to deal with the infected center; and available wheat varieties immune or highly resistant to this smut offered a promising means of control. Because of these considerations, it was concluded that reliance should be placed on the control features mentioned or on State quarantine action as needed, and that a Federal interstate quarantine should not be imposed for either flag smut or the takeall disease.

Later developments have largely justified that decision as far as this midwest flag smut center is concerned. It is true that other limited areas in Kansas and Missouri were later found to have flag smut infection. But the consistent use of resistant wheat varieties in these areas has reduced the flag smut incidence in all three States to a very low level, as indicated by a survey made in 1932 (40).

In August 1940 cases of flag smut were discovered in a limited area of the State of Washington. Observations here in 1941 and again in 1943 (25, 53) showed a slight spread to adjacent fields but no increase in intensity. No quarantine action followed this finding.

Although the flag smut situation has thus been dealt with in both the areas mentioned without resort to Federal quarantine action, this disease presents several features of quarantine interest, which at the same time lie in the field of plant pathology. 1-- As a basic food crop of the nation, wheat deserves the highest degree of protection from pest damage that can be secured; 2-- while resistant varieties were happily available in the midwest area, it is acknowledged that much of the wheat grown on the Pacific slope comes from varieties similar to the Australian types known

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[14] S.R.A. 1919, p. 85.

to be susceptible to flag smut; the resistant variety situation for eastern wheat areas has not been adequately investigated; 3-- several physiologic races are known for flag smut (58); the evidence indicates that the midwest and Pacific coast centers involve separate smut strains (26); 4-- the seed-borne nature of flag smut merits attention, particularly in the matter of developing a dependable and practical seed treatment.

Whether or not quarantine methods may be needed for this disease in future will largely depend on the results of investigations by pathologists on these flag smut relations.

The Golden Nematode

The golden nematode of potato, Heterodera rostochiensis Wollenweber, is recorded as occurring on the potato in Germany in 1881; the potato was recognized as a host there in 1909, and this nematode was set apart as a definite species by Wollenweber in 1923, thus changing its previous status as a strain of the sugar-beet nematode, H. schachtii (43). Other European records indicate its presence in Scotland in 1913, in England and Ireland in 1917, in Sweden in 1922 and in Denmark in 1928 (12). It is also reported in Holland. In Europe it has been notably damaging to potato production (8).

The golden nematode was first found in North America in 1941, associated with low yields in a few Long Island, New York, potato fields. Intensive surveys there in subsequent years indicate that the soil in about 8,000 acres of potato lands around the original center is more or less infested by this potato root parasite. Considerable search (37) in other potato producing States has failed to disclose this nematode elsewhere.

It would appear that the golden nematode was brought to Long Island from Europe about 1930. Its channel of entry is unknown. Potatoes, the logical carrier, have been excluded by quarantine from practically all of Europe since 1912 and nursery stock from abroad is required to be free from soil. It may be significant, however, that during the last three years golden nematode cysts have been recovered and definitely identified from 14 lots of soil remnants remaining around plants arriving here from European sources. (56).

The golden nematode quarantine problem need take no account of natural means of spread except in a purely local way, and its host range, being practically restricted to the potato and the tomato, simplifies the quarantine effort. On the other hand, control of the human activities, which alone are concerned in distant dissemination, involves several troublesome features.

In review of the difficulties attending quarantine action in this case, survey limitations deserve first mention, since the actually infested areas must be established with certainty before quarantine regulations are applied. In the entire absence of reliable plant symptoms we are forced to base survey on the presence or absence of the barely visible cysts. Unfortunately neither direct search on potato roots for developing cysts, nor analysis of soil samples by washing-screening methods to recover these cysts, is entirely satisfactory for scanty or incipient infestations. Both methods work well when cysts are numerous, but inability to find scattered cysts in soil or scanty infestations on plant roots, except by chance, may mean overlooked infestation spots from which spread can occur before the cyst population rises to the detectible range.

Again, total eradication, while a drastic and costly measure, would be nationally profitable, perhaps, but the field soil treatment so far used has been only about 85 percent successful in nematode kill. It is assumed here that for such an indispensable food crop as the potato almost any expenditure which would successfully suppress the nematode or prevent spread of this persistently destructive pest to other potato areas would be amply justified.

There is no evidence of outstanding varietal resistance to golden nematode. Early planted potatoes are said to escape nematode attack to some extent by making growth before soil temperature becomes favorable to nematode activity.

Rotation of crops is of small help in this case because of pronounced cyst longevity. Where the parasite persists in soil for eight or ten years ordinary rotations are scarcely practical.

Methyl bromide fumigation of tuber lots has been tried, but tuber injury is encountered before a dosage rate lethal to the nematode is reached. Chemical dips and tuber washing and brushing methods are being explored. While any successful method of tuber treatment would aid the grower to move his crop without endangering other areas, all such methods tend to discourage nematode control in the land itself, an attitude neither serving the grower's future interest, nor representing sound national policy.

It will be seen from this outline of the situation that quarantine action could not at present consider eradication, except through a long-time starvation procedure, but could undertake to prevent spread by regulation of carrier materials--potatoes; tomato plants; root crops grown on

infested soil; nursery stock, and other plants; topsoil and other soil lots; trucks, bags, crates and containers including railway cars; and local transfers of farm implements and equipment. Further, because of the populous semi-urban conditions in the golden nematode area the opportunities for spread are vastly greater than in a purely rural setting; to offset this increased danger it has been considered wise to reduce infestation at source by taking infested land out of potato production and by suppressing nematode populations in infested fields through chemical treatment.

Theoretically, quarantine action of the type here indicated, where the immense potato industries of numerous States were threatened by a destructive but still sharply localized pest, would call for a Federal interstate quarantine, supplemented by parallel action by New York State. This step was duly considered. It was clear, however, that because of the isolated character of the infested center on Long Island, and the measures that New York would be forced to adopt to protect its other important potato districts, that the State quarantine could serve for the protection of other State interests as well as its own. This arrangement has been accepted by general agreement and no Federal interstate quarantine on account of golden nematode has been issued.

Absence of a Federal quarantine connotes no lack of Federal interest in the nematode problem. Federal agencies have cooperated throughout to the fullest extent in matters of research, survey, control, soil treatment, and in the enforcement of quarantine regulations.

It should be added that State quarantines excluding potato shipments from the area under quarantine in Long Island were promulgated in 1947 by Maine, New Hampshire, and Vermont.

The relations of plant pathology to this situation have been and will continue to be important. While earlier European research was invaluable in establishing essential features for quarantine (7), it has been necessary to carry out investigations here in connection with still doubtful relations or those basic to quarantine or control practices. The Division of Nematology has given outstanding service in this field, in close cooperative relations with the research staff of Cornell University and the New York Experiment Station. In the golden nematode studies undertaken by these agencies, helpful cooperative contributions have been made by the Bureau of Entomology and Plant Quarantine, and the New York State Department of Agriculture and Markets. Important additions to knowledge obtained from these investigations include: life history and soil population studies; host range and susceptibility; the development of practical survey methods; exploration of field soil fumigation possibilities; search for effective tuber treatments; and the working out of more rapid and practical methods of cyst identification.

In the golden nematode problem, quarantine and control features seem to be closely interwoven. In both fields future success in preventing spread and providing control methods will demand extensive and patient research. Soil fumigation, and with it field control is not yet on a satisfactory basis; survey methods are much in need of improvement; tuber treatments should be more extensively studied; and the possibility of climatic limitations, important for southern potato areas, has yet to be explored.

Larch Canker

The larch canker disease due to the fungus, *Dasyscypha wilkommii*, has long been a noteworthy handicap on larch plantings in northern Europe, and great alarm was felt when this parasite was found to be present in larch plantings in three localities in southeastern Massachusetts and Rhode Island in 1927.[15]

Consideration was immediately given to quarantine action for this disease on account of the possibility that it might be carried west and there attack the highly valuable stands of Douglas-fir. European investigations had seemed to show that the true larch canker fungus and the closely related *Dasyscypha calycina* were merely varieties of a single species. The latter was common on bark of the rough-barked pines, larch, and Douglas-fir in localities where the undoubtedly parasitic canker fungus *D. wilkommii* was obviously attacking larch. Hence, there was a natural apprehension that the immensely valuable forests of the Douglas-fir in the West might be subject to attack by the larch canker organism.

However, special investigations on the larch canker situation in Europe by G. G. Hahn in 1928 and 1929 indicated that the *Dasyscypha* species found there on Douglas-fir differed from *D. wilkommii* and was evidently a weak parasite; he regarded it as a distinct species (*D. calycina*). The true larch canker fungus did not appear to cause cankers on the Douglas-fir in Europe.

[15] S.R.A. 1928, pp. 27 and 110.

Further studies by Hahn and Ayers (21) of the several Dasyscypha species present in the New England larch canker area disclosed the existence in Douglas-fir cankers of a native large-spored Dasyscypha (D. ellisiana) closely related to the true larch canker organism but determined by inoculations to behave as weak fir parasite. Inoculations in 1931 on Douglas-fir with the true larch canker species, with two other native Dasyscypha species, and with D. calycina, produced no cankers and it was confidently concluded that the larch canker fungus need not be feared as a Douglas-fir pest.

In the meantime prompt and energetic action taken by the two States concerned[16] promised effective elimination of the cankered larch plantings, and this work was virtually completed in 1932-33. Since no other infected centers were known Federal quarantine action was deferred, and when the above-mentioned research results had cleared up larch canker relations and removed the threat of damage to the Douglas-fir, the primary reason for quarantine action no longer existed and no quarantine measures were adopted then or since.

It is recognized, however, that the disease still remains a potential danger to larch plantings, and if larch should in future come into more prominence as a timber resource, control of canker and quarantine measures to prevent its spread might have to be given consideration.

Phony Peach and Peach Mosaic

Although phony disease was observed on peach in Georgia as early as 1885-1890, it was not recognized as a specific malady until about 1920 (42), and its virus character was not established until 1929 (28). Later, it was found to affect plum, apricot, nectarine, and almond. A chemical test for this virus was developed, and the incubation period was roughly determined as about 18 months or more (29). With this meager background of knowledge and the assumption that rogueing methods would be as successful as a control measure as they had proved in peach yellows, a campaign aiming at eradication was begun in 1929, supported by a domestic plant quarantine intended to prevent interstate spread through control of nursery stock shipments. Because of failure to secure infection by bud-grafting methods although root grafts readily transmitted the disease, it was concluded at that time that the virus was carried only in the root system and that nursery bud sources were a negligible element in preventing spread. On this basis the protection of nurseries was thought to be secured by keeping the nursery and the environs within one mile free from phony-infected trees.

In the absence of exact knowledge the fixing of this zonal radius at one mile represented largely an arbitrary judgment derived mainly from experience with peach yellows. This mile-zone feature has, however, been continued in the program to date; adequate knowledge on the distance of spread is still unavailable.

More recent investigations, however (32), have indicated that under some conditions the phony virus may be present temporarily, at least, in some of the foliar terminals, so that spread by twig-feeding insects can no longer be held incompatible with the root restriction above mentioned. Still other recent results (31) associate the phony virus with the woody cylinder; some portion of the vascular layer must be included with grafting or budding operations to insure successful transmission. When this relation is recognized, bud transmission has been obtained in some cases even from aerial parts of the tree.

The phony peach Quarantine No. 69, effective June 1, 1929[17], established regulated areas in Georgia and Alabama, and prohibited shipment from them of nursery stock except when grown in nurseries maintained under mile-zone phony-free conditions.

Surveys in subsequent years up to 1931, however, disclosed a widespread though less intensive occurrence of the phony disease in other States, and effective November 30, 1931, the quarantine was extended to cover all of Louisiana, Mississippi, and South Carolina, as well as parts of Arkansas, Florida, Illinois, North Carolina, Tennessee, and Texas. A continuation of survey in 1932 brought to light phony infections in Missouri and Oklahoma. This wide distribution of the disease so altered the situation that after a conference December 13, 1932, it was decided to revoke the Federal quarantine. This was effective March 1, 1933[18], although it was understood that Federal cooperation would be continued in matters of survey, research, control, and eradication.

With the revocation of Quarantine No. 67 responsibility for preventing interstate spread reverted wholly to the States, and although Federal cooperation was freely extended to the several States in their nursery and environs inspection problems, the phony control situation was not put

[16] S.R.A. 1929, p. 8. [17] S.R.A. 1929, 118-123. [18] S.R.A. 1933, 147-149.

on a generally satisfactory basis until 1936, when it was combined with the peach mosaic problem, as discussed further on.

Peach mosaic was recognized as a new virus trouble in peach in 1931 when cases coming to attention in Texas orchards were studied by L. M. Hutchins and determined by budding and grafting methods to be of virus nature (30). In 1934 the disease was reported from Colorado by E. W. Bodine (5). Since then survey has located peach mosaic in California (1933), Utah (1936), New Mexico (1936), Arizona (1936), Oklahoma (1937), and Arkansas (1947). It is known to occur also in northern Mexico.

Investigations of the relations of peach mosaic have produced evidence of the occurrence of mosaic in cultivated plum, nectarine, apricot, and almond, as well as in wild plums; some of these hosts as well as some peach varieties show transient, vague, or uncertain symptoms and may thus serve as symptomless carriers; the mosaic virus is regarded as comprising several different strains; and while an insect vector is strongly indicated, vector relations are still too indefinite to serve as a confident guide in either quarantine or control activities.

No Federal quarantine has been promulgated on peach mosaic. In 1936 Federal cooperative relations and the conditions in the various States concerned with both mosaic and phony peach were subjected to thorough review and an attempt was made to establish a single but comprehensive regulatory and control program in which each of the States and the Federal agency could participate, and which would serve alike the interests of the Federal government, the States where these diseases occurred, and the uninfected States needing protection against spread.

It may be noted that the phony peach and peach mosaic problems are very similar in that they both involve the possibility of spread by nursery stock; both require rather widespread survey activities to provide current information on incidence and spread; and in both experienced technical assistance has to be rendered to orchardists in the matter of commercial orchard control. At least two of these phases--prevention of interstate spread and survey--are to a large extent Federal responsibilities.

Federal and State resources have by general agreement been pooled in conducting nursery inspection, orchard inspection and survey as one program, jointly planned but directed by the Federal agency on account of the need for integrating these activities over a number of States. The prevention of interstate spread, essentially a matter of nursery stock supervision, could have been solved in any one of three ways: 1 -- by the promulgation of a Federal interstate quarantine on the movement of host nursery stock from the affected States, supplemented by quarantines of intrastate character by these States to take care of their own internal needs, 2 -- by an arrangement whereby the Federal authority would refrain from quarantine action, leaving the protection of uninfected States to be obtained through whatever individual quarantine measures these States wished to take, in which case the infected States would likewise be obliged to take care of their own internal protective needs and the Federal agency would enter into the situation only as an interested cooperator; 3 -- by adoption of the same cooperative relation on the part of the Federal agency, but with effective quarantine measures set up only by the infected States, the outlying States agreeing to accept such an arrangement as according them adequate protection against spread.

It is obvious that the third method is not only most economical in operation but involves the least disruption of trade practices or interference with movement. It thus represents a higher plane of quarantine efficiency, and where it can be used to advantage it is to be definitely preferred. It demands, however, careful management, the confidence of the protected States, and the deep interest and cooperation of the Federal agency if it is to succeed. This method of approach to the interstate quarantine problem was used long ago in the citrus canker campaign, again in the potato wart problem, still more recently in the golden nematode plans.

This third method of putting into effect the regulatory features of the peach diseases program was selected and widely approved in 1936 as the simplest and most feasible means for the prevention of spread in this case. It may be added that it has worked well and that there has been yet no evidence of interstate spread through the movement of nursery stock in either the phony peach or mosaic areas.

In the current peach disease project, therefore, prevention of spread, orchard control, and survey functions are inextricably interrelated. The experienced inspectors contributed by both the Federal agency and the infected States are utilized under Federal supervision according to the season in the inspection of nurseries and their one-mile environs, as well as of budwood sources and their environs in the mosaic areas. Later these inspectors examine commercial orchards and mark diseased trees for removal, and as opportunity offers, inspection of the survey type is made in outlying areas to keep a check on phony and mosaic development outside of the known infected territory.

A report is made by this inspection service on the disease conditions found in and around nurseries and budwood sources in each State, and this report is the basis on which the State grants or withholds the certification required under the general arrangement for interstate nursery stock movement.

In summarizing the regulatory aspect of this phony peach and peach mosaic project, several features stand out clearly--the absence of a Federal quarantine; the adoption of a practically uniform series of quarantines by the affected States; the close cooperation of the Federal agency with each State concerned, not only in its regulatory control of nursery stock intended for interstate movement, but in orchard control and survey activities as well; and the avoidance by numerous other peach-growing States of the need for a host of individual State quarantines diverse in content and difficult to enforce effectively.

A recent very important contribution in the phony peach problem (54) establishes as phony vectors at least three insect species in the leafhopper group. This accession to knowledge not only throws light on a key feature of this perplexing disease but also indicates likely paths for other research efforts, which in turn may profoundly benefit the future control program.

Vector relations in peach mosaic are still under investigation. Tests conducted at the Colorado Agricultural Experiment Station (13) indicate that the green peach aphid (Myzus persicae) may be at least one effective agent of mosaic transmission.

From the pathologist's viewpoint these peach virus diseases still need much investigation to put control and regulatory features on a sound footing. More light is urgently needed on host ranges, reservoir hosts, symptomless carriers, vectors and their relation to spread, season, and mode of infection, and virus strain relations.

Powdery Scab Quarantines

The powdery scab organism, Spongospora subterranea, was known to exist in European countries at the time of the passage of the Plant Quarantine Act in 1912, and steps were taken (Quarantine No. 11, effective December 30, 1913) to exclude foreign potatoes on account of this and other pests.[19] Late in 1913 the powdery scab disease was found on potatoes in Maine in a limited area near the Canadian border. A conference on this situation was held in Washington, February 26, 1914, and arrangements were there concluded to have Maine control this still very limited outbreak by a system of State inspection and certification. However, more powdery scab soon began to appear in Maine, and on April 25, 1914, a Federal Domestic Quarantine (No. 14) was imposed on the State.[20] Still further search disclosed powdery scab in northern New York and that State was likewise placed under a similar quarantine on November 14, 1949 (No. 18).[21] Federal regulations to govern the movement of potatoes out of the quarantined areas of these two States were set up, involving a system of inspection and certification.

Knowledge on the nature of the scab organism and its distribution was woefully deficient up to that time, and we must understand that the quarantine action thus taken so promptly represented a sincere effort to protect the country's interests under apparently threatening circumstances.

Extensive survey activities were undertaken immediately and these disclosed little or no powdery scab outside cool northern areas. Evidence was rapidly accumulated also which established the inability of the parasite to survive under warm southern conditions; seed potatoes well infected with powdery scab could be shown to produce a clean crop in a warmer environment. Consequently a rapid change in attitude took place. Instead of regarding these northern outbreaks as dangerous recent invasions from Europe likely to spread devastatingly, they soon came to be looked upon as probably long-existent centers naturally confined to colder areas, and hence relatively harmless to the rest of the nation's vast potato cultures.

As soon as these relations were reliably established, both powdery scab quarantines (Nos. 14 and 18) were promptly revoked by an order of August 30, 1915, effective September 1, 1915.[22]

This early quarantine attempt demonstrates clearly the need for adequate pest information as a sound basis for quarantine action and emphasizes also the difficult quarantine decisions that an administration may be compelled to make in the absence of sufficient knowledge.

Potato Wart

The potato wart organism (Synchytrium endobioticum (Schilb.) Perc.) was probably introduced into this country in several shipments of European potatoes imported in the winter of 1911-12 to relieve a temporary crop shortage in the Eastern States. These were widely distributed in these States, mostly to heavy population centers. Some of these potatoes were doubtless

[19] S.R.A. 1914, p. 9. [20] S.R.A. 1914, p. 19; p. 31. [21] S.R.A. 1914, p. 82. [22] S.R.A. 1915, p. 57.

planted or their peelings and waste found their way to town and village gardens, thus establishing scattered wart infections in local soil over a wide area. When wart was discovered in Pennsylvania in 1918 (47) extensive surveys indicated its presence in many counties of that State and in limited portions of West Virginia and Maryland (35). Although the original European shipments had been widely distributed elsewhere, wart was found to be confined to cold mountain top areas, largely non-agricultural, thus raising the suspicion of a climatic limitation.

European experience indicated the existence of varietal resistance amounting to practical immunity, and several widely grown American potato varieties were soon found to possess a similar immune character. Being entirely soil-borne, wart could be spread only by human activities involving movement of infected tubers or contaminated soil. In Europe the wart disease had been seriously destructive to susceptible potatoes and infested the soil for many years.

The potential threat of such a disease to our second important national food crop was recognized early, and Orton and Field in 1910 (44) made an urgent plea for the exclusion of European potatoes to prevent its introduction. This dangerous situation was so well understood by responsible State and Federal leadership by 1912 that there was included in the Plant Quarantine Act passed that year a provision for immediate quarantine action against potato wart, along with white-pine blister rust and the Mediterranean fruit fly. Foreign Quarantine No. 3 on this disease was thus issued effective September 20, 1912, before the general effective date of the Act itself on October 1.

Upon discovery of potato wart in 1918 in the three States mentioned, the question of a Federal domestic quarantine to prevent interstate spread was immediately considered. Before such action could be taken, however, it was necessary to conduct a widespread and intensive survey based largely on available records of the 1912 European potato distribution destinations.

As survey results built up a picture of an unexpectedly limited wart occurrence, and as the energetic action undertaken by the three affected States appeared to promise ample safeguards in the relatively simple problem of preventing spread, either locally or to other States, the need for Federal quarantine action seemed less and less imperative. The final outcome of these developments was a general agreement to forego a Federal quarantine and to rely on adequate State quarantines carried out with Federal assistance and cooperation. This policy has continued unchanged to date.

The quarantine attitude adopted in this case represents an early example of the increasing present tendency to depend wherever possible on the quarantine and regulatory efforts of a State to prevent spread of a specific pest, both within its own borders and to other States, rather than to rely on measures in the State of destination or on Federal interstate quarantines.

This preference for local action in Federal-State quarantine relations, wherever State measures can adequately meet the situation, does not signify Federal disinterest or lack of cooperation in such problems. Outside of purely quarantine aspects the Federal agencies may still participate actively in research and survey activities, as well as generally looking after the interests of other States likely to be affected. This has been the Federal role in potato wart.

Contributions in the field of plant pathology which have materially affected quarantine plan and procedure have been many and varied. Many pathologists in Federal and State agencies and institutions participated in the extensive early surveys for this disease. Since then survey has been continued in the affected States by State effort, particularly in Pennsylvania where a large part of the State has been systematically examined for wart over the years. No evidence has appeared which would indicate that distant spread has taken place from the areas under quarantine (2).

Early interest in the utilization of immune varieties led to the testing of all available commercial American potato varieties (22, 23), as well as some of the more promising European sorts. Further, all new varieties developed by the Bureau of Plant Industry, Soils, and Agricultural Engineering are tested for their relation to the wart disease as a routine procedure. These tests involve planting for a season in garden soil in Pennsylvania kept heavily infected with the wart organism, under the supervision of the State's wart control personnel.

The great longevity of the wart organism in soil has been indicated by observations in Europe and in this country. Field observations and experiments have been conducted in Pennsylvania since 1927 by the State Bureau of Plant Industry to determine how long wart will persist in soil under various cultural conditions. These studies were summarized at the end of 1949 by R. E. Hartman, pathologist, in charge of wart control activities for Pennsylvania during this period:

"There appears to be no definite period of wart persistence in soils. Our records in Pennsylvania indicate that, while wart is known to have survived for 25 years in one case in land under permanent sod, the organism disappeared in 10 years from an

experimental plot maintained in sod and tested annually for wart persistence. Where the soil is cultivated yearly or kept under fallow conditions, wart seems to die out more rapidly--in 6 seasons in several experimental plots, and apparently in similar periods in gardens planted to vegetables or with immune potato varieties. It is suspected that the available oxygen supply is a factor in hastening spore germination in soil and thus reducing longevity."

Survey indications of a wart relation to low soil temperatures have been confirmed by a series of soil temperature records carried out for several years in Pennsylvania and by potato inoculation tests made there under various constant temperatures. The results place the upper limit for wart persistence at about 70° to 72° F. This permits a general correlation of wart with areas having a frost-free growing period of 140 days or less. This relationship indicated on a map of the United States will suggest those areas where potato wart is likely to persist (36).

An early phase of investigation attempted to develop practical heat and chemical soil treatments for infected garden plots. Many of these successfully killed out the wart organism (55).

Reports from German sources (6) indicate the presence there of biologic races of the potato wart fungus which are said to attack some of the potato varieties normally regarded as immune. Since the only practical field control of potato wart lies in the fortunately ample list of known immune varieties (22), the ominous implications of this race plurality deserve the close attention of pathologists.

The outstanding feature of the potato wart situation is the eradication campaign well on the way to completion in Pennsylvania (35) and now initiated in both Maryland and West Virginia. A number of methods of destroying the wart organism in infected soil were developed at the outset (27), but none of these could be put into effect on a field scale until the distribution of wart was more certainly determined by survey. This stage was reached for the Pennsylvania wart situation about 1930. Since then a long-time highly successful program for the suppression of wart in successive areas has been undertaken. Present prospects are for its completion in the State by 1952. The Pennsylvania program takes advantage of natural wart disappearance from the soil and the abandonment or obliteration of many infested gardens in coal mining operations; in addition gardens are treated with about one ton per acre of copper sulfate, which has proved practical and effective for eradication purposes. To effect the elimination of a soil-borne organism of this persistent type from such numerous individual gardens scattered over a large area is an unusual and distinctive accomplishment.

The wart problem presents another feature of interest to pathologists. A special committee of the American Phytopathological Society appointed to study plant disease matters of quarantine interest has been asked by the Bureau of Entomology and Plant Quarantine to examine the wart situation and present suggestions and recommendations on plant quarantine policy and relations.

White-Pine Blister Rust

The pronounced susceptibility of our American white pine species (*Pinus strobus*) to the white-pine blister rust (*Cronartium ribicola* Fischer) was well established in the closing years of the last century by observations in Europe, where this excellent timber tree was being tried out by progressive European forestry organizations. Because of abundant occurrence there of the necessary alternate hosts (*Ribes* spp.) and particularly the very susceptible European garden black currant (*Ribes nigrum*), damage to white pine nursery stock and planted seedlings was so severe as largely to discourage the use of this otherwise very desirable timber species.

Reports in European journals and urgent warnings issued by forest pathologists returning from European visits served to drive home the impending threat of devastation to one of our most valuable timber resources should this disease become established in America. At that period much effort was already being directed to reforestation of the extensive eastern areas where forest wealth was rapidly vanishing because of fire losses and reckless and destructive utilization.

While these earnest warnings stirred little popular feeling on the subject they were effective enough among thoughtful and farsighted leaders, and the discovery of the disease here in 1906 aroused sufficient interest to have the white-pine blister rust included as a prominent reason for passage of the Plant Quarantine Act in 1912 In fact, that Act included a special provision for immediate promulgation of quarantine protection in the case of blister rust and potato wart. The Act in general became effective October 1, but quarantine action on these two subjects was permitted immediately after the date of passage August 20, 1912.

This step toward exclusion was too late, however; the rust was already in the country, having

apparently been introduced in large shipments of nursery seedlings of white pine and widely distributed in a number of Eastern States and adjacent parts of Canada. From a number of independent rust centers thus started, local and distant spread has disseminated the fungus into practically all commercially important white pine areas. It became and still remains a domestic plant quarantine problem.

The first Federal Domestic Quarantine on white-pine blister rust (No. 26) was promulgated, effective June 1, 1917. It quarantined all States east of and including Minnesota, Missouri, Arkansas, and Louisiana, and prohibited the movement of five-leaved pines or currant or gooseberry plants out of the quarantined area; it further prohibited movement of five-leaved pines or black currants out of Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island, and New York--the area then regarded as actually infected.

At this time hopes were entertained that it might be possible to delay or prevent extensive spread of the blister rust, and to control it locally in the infected portions of eastern forest areas. Protection of the western white pine areas was also regarded as imperative, and the restrictions on shipment from the quarantined Eastern States were intended to prevent spread into the Pacific region.

Delay in establishing a domestic interstate quarantine until 1917 arose from a defect in the original Plant Quarantine Act which prevented the application of Federal quarantine regulations to a portion of a State.

The necessity of considering the State as a unit in any Federal action so that quarantine restrictions applied alike to infected and uninfected areas within it, involved such obvious injustice and hardship to noninfested areas that establishment of a workable quarantine measure had to await a revision of the Act on March 4, 1917, which permitted restriction of the regulations to State areas actually affected by the pest, and designated as regulated or control areas.

The discovery of blister rust in southern British Columbia and in nearby Washington State late in 1921 made real the previous potential threat to the white pine areas of the West. An additional quarantine, No. 54, effective March 15, 1922, was promulgated to protect Washington and other Western States from spread out of the then known 19 infected counties of Washington. The evidence indicates that this west coast outbreak did not arise from numerous introduction centers as in the east, but was traceable to one lot of diseased white pines imported from Europe into British Columbia in 1910.

In subsequent years extensive spread took place in both East and West, and it was soon recognized that blister rust would eventually reach all susceptible white pine areas where the ribes hosts were present because of the wind-borne nature of the rust. To accord with this viewpoint the quarantine aims and procedures underwent some modifications which were embodied in a single new Nation-wide measure, Quarantine No. 63, effective October 1, 1926. This quarantine amalgamated Quarantine No. 26 with Quarantine No. 54, and extended the scope of the combined measure to include the entire continental United States. It retained the provisions for protecting still unaffected areas in both East and West against rust introduction by host movement in advance of natural spread, but in general it geared its restrictions and requirements to supplement and serve the needs of the nation-wide control program based on elimination of ribes hosts growing near pines.

Further revisions were made in Quarantine No. 63 or its regulations, effective July 1, 1938 and on July 1, 1946. These introduced certain procedural changes and modifications helpful for administrative purposes, but they have left essentially unchanged the basic relation of the quarantine and its regulations to the control program.

The progress already made toward protecting the country's white-pine timber resources from blister rust damage represents a high national achievement in the pest control field. In spite of the gloomy prospect which faced us a quarter of a century ago, white pines, our most highly prized forest trees, are now reseeding and flourishing over thousands upon thousands of acres which once seemed doomed to produce only inferior forest species. Regarded in proper perspective the time, money, and effort spent in this large-scale control undertaking will pay off handsomely to the Nation in the years to come.

The part played by regulatory features in this program has been largely supplementary, not dominant. In a true sense the blister rust campaign throughout its course has been a community effort, not solely a Bureau project. It would have been impossible without the generous assistance of numerous States, the contributions of many counties and municipalities, the cooperation of forestry and lumber interests, the public-spirited attitude of innumerable community leaders, the willing participation of a host of individual land holders large and small, and especially the invaluable contributions of many plant pathologists in Federal, State, academic or private service all over the country.

It may be appropriate here to review briefly some of these contributions which have had important influence on the quarantine viewpoint. It is impossible in this limited article to list the numerous contributions in this field; mention can be made only of research features which have importantly furthered quarantine understanding and bettered procedures. Reference may be made, however, to the extensive compilations of literature prepared by Spaulding (49, 50); by Fulling (15); and by Mielke (39), the last named dealing especially with the blister rust problem in the Western States.

The recognition about 1916 of the weak and localized nature of spread of the ribes sporidia to pines had obviously a most important bearing on the situation. Determination of the effective sporidial range underlies not only the extent of the ribes-free zone needed for pine protection but also enters directly into the problem of white pine nursery production.

Of almost equal importance were the studies and observations on wind dispersal of urediniospores and aeciospores which, along with numerous infection experiments, established relations of extremely practical value in field control plans.

Host species range and species susceptibility had to be worked out for both pine and ribes groups. Studies of the weather conditions under which pine and ribes infections occur, together with the later course of development of such infections, supplied information of great practical control value. The conclusion reached early that the ribes rust stage may for all practical purposes be regarded as nonwintering on this host had a material effect on both control and quarantine planning.

Contributions to our knowledge of survey methods have been numerous. These have tended definitely to increase efficiency or to lower costs of operation. Careful studies of ribes habitat, species peculiarities, methods of eliminating these hosts cheaply and completely, have been invaluable to the program. Of special interest have been investigations on seeding habits, root-sprouting behavior, checking on ribes recurrence, and the use of herbicidal chemicals in eradication work.

Woodgate Rust

The Woodgate Rust Quarantine No. 65 was imposed, effective November 1, 1928, on nine counties in northern New York to prevent spread of this gall-forming rust (*Peridermium* sp.) from the only region then known to be attacked by this parasite on Scotch pine (*Pinus sylvestris*) and other hard pines. Concurrent with this quarantine, regulations were issued which in effect prohibited movement out of the regulated area of trees, branches, limbs, and twigs of Scotch pine or other hard pine species.

This action was taken, it was stated, not so much to protect the particularly susceptible Scotch pine in plantings elsewhere, but to prevent spread of this damaging disease to other hard pine species of the Southern and Western States. While less subject to infection than Scotch pine, various other hard pines were much more valuable timber trees.

This quarantine continued in effect until July 31, 1939, on which date it was revoked together with its regulations. It was then explained that several years of observation indicated that this rust did not spread aggressively and that its threat to the country's hard pine species did not seem serious enough to warrant continuation of the quarantine.

From the point of view of plant pathology the Woodgate rust situation presents certain features of interest. This rust was found in the vicinity of Woodgate, New York, in 1925, on Scotch pines. These showed in some cases a heavy gall production which evidently interfered with normal tree development. Annular ring studies of gall tissue indicated a long-standing infection. The galls of Woodgate rust can be distinguished only with difficulty from those common on Scotch pine due to *P. quercina* (= *P. cerebrum*). Survey thus becomes largely a technical operation. It was established, however, that infection could take place from the pine aecial stage directly to other pines; no alternate host is concerned. Inoculation studies on other hard pines gave rather poor results and a low rate of infection in general.

Many of these features and relations came to light subsequent to the promulgation of this quarantine. But however much these later contributions may have clarified knowledge of the Woodgate rust situation, the chief weakness of the quarantine did not lie in these unknown biological factors so much as in the poor adaptation of the quarantine plan to its intended objective. There was, it is true, one nursery in the regulated area likely to grow and sell pine trees; its activities could readily have been controlled by the State in the normal course of nursery inspection routine. Aside from this means of rust dissemination there remained only two channels: 1 -- the carrying away of trees, limbs or branches by casual visitors; 2 -- wind dispersal of spores. The latter was entirely outside of quarantine control, since no attempt to suppress galls

or aecial formation in the infected area was included in the program. As far as trees and gall-bearing limbs were concerned, these seldom or never moved in public carrier channels where quarantine control would be effective. Any movement of such materials interstate would almost invariably involve occasional and wayward transport by private individuals, and over this type of movement no effective supervision was provided.

In this case, therefore, the quarantine was soon found to have a low protective value, not primarily because of any lack of technical knowledge, but because the quarantine procedure itself could accomplish little in a practical way in preventing spread.

The situation ten years after the revocation of the Woodgate rust quarantine has tended to confirm the apparent inertia of this rust and to class it as a pine disease of sluggish habit and minor importance.

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DIVISION OF DOMESTIC PLANT QUARANTINES, BUREAU OF ENTOMOLOGY AND PLANT QUARANTINE, AGRICULTURAL RESEARCH ADMINISTRATION

PLANT PATHOLOGICAL RESEARCH IN GEORGIA

B. B. Higgins

The Georgia Experiment Station was established August, 1888, and plant diseases were among the first agricultural problems to receive attention. This may appear surprising, since in public institutions, such as the State agricultural experiment stations, fields of research nearly always follow rather than precede public interest.

Brief perusal of agricultural publications prior to the establishment of the experiment station shows real farmer interest in plant diseases even at an earlier period. The Central Agricultural Society (changed to Georgia Agricultural Society in 1852) held a fair each year with valuable prizes for the best exhibit of each agricultural product, and required the grower to report the variety and the method of growing the crop. In compliance with this requirement in connection with an exhibit of wheat, about 1850, D. Ponce reported that the seed was soaked 12 hours in bluestone solution, one pound bluestone to five bushels of wheat, drained, spread on a floor, and dusted with hydrated lime. Numerous references to losses from black rot of grapes, rots of peaches and of apples, and from various other plant diseases, with occasional reports on attempts to control them, are recorded in the "Transactions" of this society.

In view of this farmer interest, it is not surprising to find the very first experiment station staff devoting considerable effort to obtain better control of plant diseases. They were not trained pathologists, but their work in pathology deserved the research designation perhaps as much as that in other lines at that time. Gustave Speth, the first horticulturist, published in 1891 a bulletin on small fruits with a single page devoted to diseases. The following year, he published one on culture of sweet potatoes with a report (two pages) on attempts to control black rot, and one on tomatoes with a three-page report on fruit rot (blossom-end rot). He was succeeded as horticulturist in 1893 by H. N. Starnes who published on diseases of grapes, diseases of Irish potatoes, and diseases of blackberry and dewberry; but these reports contained no experimental data. However, a report on peach maladies did contain experimental data on the effect on peach foliage of Bordeaux mixture at varying concentrations and with varying proportions of Paris green or of London purple added. In January 1899, Starnes was succeeded by A. L. Quaintance, with the title of biologist and horticulturist. Quaintance remained less than three years, but in this time did an enormous amount of experimental work on control of insect pests and diseases along with the general work with horticultural crops. He published a synoptical, tabular description, including relative susceptibility to black rot, for 302 varieties of grapes, and short articles in the Annual Reports summarizing work on control of grape black rot, Macrosporium blight of tomato, and on celery blight. His bulletin on brown rot of stone fruits was a more extensive contribution.

Quaintance was succeeded, in October 1901, by S. H. Fulton, who remained less than a year, but completed and published a study of cantaloupe varieties and diseases that had been started by Quaintance.

On August 15, 1902, H. N. Starnes returned to the station and in 1904 and 1905 published two bulletins on plums, including considerable discussion of diseases in each.

Following passage of the Adams Act in 1906, a Department of Botany and Plant Pathology was established, and R. J. H. DeLoach was appointed to head the department on January 1, 1907. DeLoach remained less than two years, but published a bulletin on cotton anthracnose.

He was followed in October 1908, by C. A. McLendon who remained until October 1913. McLendon devoted full time to cotton breeding and carried no research in plant pathology. During this period, J. M. Kimbrough, agronomist, reported that adequate potash applications greatly reduced incidence of so-called cotton rust, thus indicating the disease to be due to potash deficiency. Also, H. P. Stuckey, horticulturist, and J. C. Temple, bacteriologist, cooperated in a study of tomato blossom-end rot, which demonstrated for the first time the real cause of the disease to lie in the water relations of the plant. They were also interested in and had started preliminary investigations to determine the etiology of plum wilt when B. B. Higgins came to the station as botanist and plant pathologist in October 1913, and the problem was turned over to him.

About the turn of the century, interest in commercial plum growing was almost as great as that in peach growing. In 1904, nearly a million trees were reported in Georgia orchards; but by 1913 the industry was practically dead and most commercial orchards had already been abandoned, owing to plum wilt, bacterial leaf-spot and canker, and cold injury, wilt being far the most serious. It was hoped, therefore, that an understanding of the disease might suggest practical control measures that would allow the industry to become reestablished. However,

finding that the disease was caused by a fungus which could, and did persistently, enter through pruning wounds, borer wounds, cankers from cold injury, or any wound which admitted the fungus to the heart wood of the tree; did not suggest any practical method for controlling it.

The conspicuous gum exudation and the relation of gum formation to spread of the causal fungus through the tree led to a study of gum formation and wound healing of woody plants in general.

During this period several minor problems were investigated: diseases of collards, a microstroma disease of pecan catkins, the value of spraying Irish potatoes under Georgia conditions (with hopper burn and early blight the principal diseases), resistance to nematode in peaches, resistance to blight of Pineapple pear, and rosette of peach.

During the period of the first world war, the pimiento canning industry was developing about Griffin, Georgia, and by 1920, a considerable acreage was grown under contract in this area. Little was known about diseases; no disease control measures were used in the plant beds, in the fields, or in the cannery where seed were saved; consequently, losses were severe. In an effort to help an infant industry, an intensive study of pepper diseases was begun in 1920, studying the etiology, and the control of all diseases occurring locally. The diseases found sufficiently destructive to justify control measures were: damping-off, southern blight, mosaic, Cercospora leaf-spot, bacterial spot, anthracnose, and blossom-end rot. Later (1929) a fruit rot caused by Vermicularia capsici Syd. was observed in the area about Macon, Georgia, and was described under the name "Ripe rot." It has now spread over the entire State and, during rainy seasons, is the most destructive of all pimiento diseases.

Space will not permit discussion or even mention of studies of the various diseases and control measures indicated from these studies; but the fact that seed treatment was found an effective and cheap method of controlling several of the more serious pepper maladies is of interest. The studies with pepper seed treatments indicated the desirability of treating seed saved from fleshy fruits before drying, if a liquid treatment was to be used. Later this recommendation was found to be applicable to tomato, cucumber, cantaloupe, watermelon, etc., and treatment of the freshly harvested seed of such crops has come to be the general practice among the better class of seed producers. The work with pepper seed also led to cooperative relations between the Georgia Experiment Station and the manufacturers of seed-treating materials. This cooperation was continued through several years and was mutually helpful to the manufacturers and to the experiment station workers. Results from studies and the resultant stimulus for similar work in other institutions on disease control by seed treatment constitutes, probably, the most valuable contribution to plant pathology made from the Georgia Experiment Station.

In 1923, a root disease of cotton came to our attention; and, because of its general distribution, investigation as to its cause and possible means of control were started the following year. The disease symptoms were found to be due to growth of Fusarium moniliforme on roots of the young plants. Spores of this fungus were found almost universally present on cottonseed. Treating acid delinted seed with mercuric chloride solution completely destroyed the seed-borne spores and in sterile soil the treated seed produced healthy vigorous seedlings; but in the field plantings seedlings from surface sterilized seed showed 50 to 90 percent infection with F. moniliforme, owing to the abundance of the fungus in our cultivated soil. The treatment appeared to destroy seed-borne organisms, including Glomerella gossypii and Bacterium (Xanthomonas) malvacearum, as had already been reported by other workers.

In order to surface disinfect cottonseed with a solution, it was necessary to remove all lint from the seed, a job not easily accomplished. Although chemical delinting had been recommended by Barre and others some years previously, growers would not delint their cottonseed with sulphuric acid. Furthermore, we found that delinted seed germinated poorly in cold wet soil. Development of a satisfactory dust disinfectant was therefore made the primary objective in this project. Copper carbonate, the only dust disinfectant commercially available, was found ineffective for disease control and seriously injurious to cottonseed. Numerous dusts were prepared in the laboratory, including many mercury and copper salts precipitated on talc or on finely divided coal dust, various aniline dyes, etc. At the same time the Bayer Company and DuPont Company started submitting, for test, numerous preparations containing organic mercury compounds. By the summer of 1927, the feasibility of controlling seed-borne diseases of cotton by the use of chemical dusts was thoroughly demonstrated. Some of our own mercury dusts and one submitted by DuPont had given perfect control of seed-borne, angular leaf-spot bacteria. These results were reported in two articles published in Phytopathology; but the investigation was continued in order to examine the properties of the numerous fungicidal dusts that were being submitted by various manufacturers. By 1931, nearly 100 dust materials had been tested. A few dusts containing mercury were the only ones found to control seed-borne

diseases effectively without reducing viability of the seed. Comperative yield tests throughout these years indicated that the per plant yield of cotton from effectively treated seed was significantly higher than that of plants from untreated seed, because of freedom from disease. Considering effectiveness of disease control, improvement of germination, and cost, 2% Ceresan and another DuPont dust, later given the name New Improved Ceresan, were distinctly superior to all others and use of 2% Ceresan on cottonseed was recommended. After two years further test, New Improved Ceresan was also recommended, with the caution that it would retard germination under certain conditions, especially when used in excess of recommended rate.

Following the demonstration of the possibilities of dust treatment of cottonseed in 1927, pathologists in most of the cotton states started similar investigations and their results supported the Georgia conclusions. In 1936, a Cotton Seedling Disease Committee was organized with more than half the cotton states participating. This committee has continued actively testing all promising new chemical dusts suggested for seed treatment; but to date, nothing has been found that equaled the organic mercurials in effectiveness. However, the widespread interest in this field of work did hasten farmer acceptance of the recommendations, and today cottonseed treatment is routine practice throughout the cotton belt. Yearly, it adds millions to the income of cotton growers through improved stands and increased yields.

During the late twenties, investigations were also carried out on bed rot of sweet potatoes (Sclerotium rolfsii), on halo blight of beans and kudzu, and on the diseases of cantaloupe. The latter study was concerned principally with cucurbit downy mildew and a practical method for controlling it. Under Georgia conditions, the cantaloupe crop is severely damaged by downy mildew (Pseudoperonospora cubensis(Berk. & Curt.) Rostow) about one year in four, but there was some doubt as to the economics of following a regular spray schedule on cantaloupes. During the study, data were accumulated indicating quite definitely that the causal fungus lives over winter, principally on cucumbers, in south Florida, and is spread up the coast, by winds, during periods of cool humid weather. Several sprays and dusts were tried, but none were satisfactory. Cantaloupe foliage is extremely sensitive to sulfur and all copper sprays and dusts available at that time damaged the foliage and delayed fruit development so much that there was rarely any significant profit from spraying. The information gained during this study has led finally to the current cantaloupe breeding program at the experiment station.

The large-scale field production of tomato and other vegetable plants in the coastal plain of Georgia for shipment to more northern regions got underway in the Tifton area about 1914. Tomato seed were sown about the end of February and, growing slowly over a period of eight weeks, the plants had ample time for the development of disease symptoms before reaching the northern purchaser. After a few years, complaints began pouring in; and by 1925, some of the tomato canning states were threatening an embargo against Georgia-grown plants. Some preliminary investigations by O. C. Boyd, of the State Board of Entomology, indicated that the complaints were due to seed-borne diseases and that the causal organisms were present on the seed furnished the growers. Intensive investigations were started the following year by Frank Van Haltern of the Georgia Experiment Station. He found Alternaria solani, Septoria lycopersici, Aplanobacter (Corynebacterium) michiganense, and Xanthomonas vesicatoria commonly present on commercial tomato seed, some lots producing 40 to 50 percent diseased seedlings. None of these except the Alternaria appeared capable of living over in the soil under ordinary methods of handling the plant fields. Alternaria was found to live over one year and possibly two years under certain conditions. After four years study, it was found that very satisfactory tomato plants could be produced by saving seed from fields showing a minimum of disease, treating the seed before planting, planting in fields that had not grown a solanaceous crop during the previous two years, spraying at least three times before pulling the plants, and using a few ordinary sanitary precautions in pulling and packing the plants. In 1937, the United States Department of Agriculture established a pathological laboratory at the Coastal Plain Experiment Station, Tifton, and has continued the work until the present time.

During the thirties, several other pathological problems were studied. Oat smut was yearly causing serious losses, because many farmers refused to use the formaldehyde method of seed treatment. A large number of dust and liquid treatments were compared over a period of years and New Improved Ceresan dust recommended in 1936.

The mycorrhiza of pecan roots was studied because of its suspected relation to pecan rosette. Five types of mycorrhizal mantles were recognized and the fungi associated with three of these identified. It was found that healthy vigorous trees always had abundant mycorrhizal roots, while rosetted trees had few feeder roots of any kind and few or no mycorrhizae, although this condition appeared to be a result of the nutritional disturbance associated with zinc deficiency rather than the cause of rosette.

During the winter of 1927-28, cold injury to peach trees was severe. Observations on trees in a fertilizer test indicated that injury was inversely correlated with vigor, being least severe in blocks receiving fertilizer with high nitrogen ratio. Since this observation was not in agreement with prevailing horticultural recommendations, an investigation was initiated in cooperation with the Bureau of Chemistry and Soils, U. S. Department of Agriculture. The results confirmed the original observation and indicated that the best insurance against cold injury lies in maintaining vigorous growth in the trees.

The erratic behavior of cotton varieties in their susceptibility to Fusarium wilt had been a serious problem confronting the cotton breeder as well as the pathologist until injury to cotton roots by meadow nematodes was noted in several Georgia test fields in 1938. In these fields the most wilt-resistant varieties became quite susceptible, and the same behavior was noted when soil of a test field was infested with root-knot nematode and Fusarium. Considerable variation in susceptibility to root-knot damage was found among cotton varieties. This work was done in cooperation with the United States Department of Agriculture in connection with a cotton breeding project.

An investigation of the root-rots of snap beans developed the information that in Georgia snap beans are subject to several root diseases that shorten the life of the plants and caused by: Sclerotium rolfsii, Macrophomina phaseoli, Rhizoctonia solani, and the root-knot nematode Heterodera marioni. The study helped to clarify the relation between Macrophomina and the sterile condition of the fungus known as Sclerotium bataticola, and some valuable information concerning other bean diseases was obtained; but little resistance to these diseases, especially to Sclerotium rolfsii, was found in any variety of beans and the breeding program was soon abandoned.

This brings us to a discussion of the present program of work at the Experiment Station: 1. Peanut breeding and peanut diseases; 2. Diseases of muscadine grapes; 3. Breeding watermelons for resistance to wilt; 4. Breeding cantaloupes for resistance to diseases; 5. Breeding tomatoes for resistance to wilt and root-knot nematode; and 6. Diseases of pasture plants.

The work on peanuts is the oldest and the most extensive of the current projects and a discussion of its development will serve to illustrate the devious turns a research project may take when benefit to the farmer is the principal motivation.

During the late twenties, there were constant complaints to the Experiment Station on the heavy losses suffered because of peanut diseases, principally leaf spots and southern blight (Sclerotium rolfsii). Our experience with seed treatment as a control for cotton diseases led to a study of its efficacy in controlling peanut leaf spot and tests were started during 1928. The results showed that shelling and surface-sterilizing the seed had little effect upon the incidence or severity of leaf spot when the plants were grown in open air. By 1931, peanuts were selling as low as $30 per ton. The grower could not afford dusting or spraying in the field because of the low acre value of the crop; and the development of disease resistant varieties with nut characteristics to meet market demands appeared to be the only practical solution. Nearly a hundred varieties and strains from all peanut growing areas were assembled and the breeding work was started in 1931. It is still going on an extensive scale. Several hundred foreign varieties have been added to the collection for study, but none have been found to have any marked degree of resistance to either leaf spot or to southern blight. At present, the wild species of Arachis from South America are being assembled and studied as to their possible genetic value. Some of them appear to be quite resistant to leaf spot diseases.

Along with the breeding work, the common diseases have been studied as to cause and control. It was found that there were two distinct leaf-spots produced by distinct species of Cercospora. The life history of each species was followed through, and the ascigerous stage of each discovered and named: Mycosphaerella arachidicola Jenkins (Cercospora arachidicola), and M. berkeleyii Jenkins (Cercospora personata). Following the excellent results from spraying and dusting peanuts reported from Virginia and North Carolina, tests were started with the Spanish variety in 1937. Consistent and profitable yield increases were obtained from dusting with either sulfur or copper-sulfur (10-90) mixture; and, with increase in price of the crop, growers adopted the recommended practices and dusting is now fairly general.

Observations in peanut fields throughout the coastal plains area suggested poor stand as probably the most important factor responsible for low average yields in Georgia; and caused the resumption of seed-treatment studies with improvement in viability and final stand as the objectives. Yield records were obtained indicating that surface disinfection of the seed had no effect on yield per plant, and seed-treatment for peanuts with 2% Ceresan was recommended for improving stand. After further tests, comparing results with several materials, Arasan and Spergon were recommended for use where the dosage could not be measured accurately, since overdosage with 2% Ceresan sometimes injures the seed. When used on good seed stock, the

improvement in germination from Arasan and Spergon treatment is usually not significantly less than that from 2% Ceresan; but with seed of low vitality or seed severely damaged in shelling, 2% Ceresan is usually significantly superior to any other material tested. Arasan and Spergon at the recommended dosages are not very effective fungicides. Their beneficial action appears to be associated with their anti-oxidant properties.

"Concealed Damage" of runner peanuts was first brought to our notice in 1937. It was found to be caused under certain conditions by most any of the common molds present in the soil, especially when peanuts are harvested during periods of high temperature and high humidity.

Much effort has been expended in trying to discover some means of reducing the losses from Sclerotium rolfsii in peanuts as well as in other crops; but to date these efforts have not been particularly fruitful. Proper crop rotation preceding very susceptible with immune or less susceptible crops is of some value. Chemical soil treatments are being investigated. One phase of the disease, "Blue-black" discoloration of Spanish peanuts, develops in stacks and even in bins of threshed peanuts, infected with S. rolfsii, if moisture remains high for a few days.

Peanuts are damaged by several species of nematodes. An effort is being made to determine the extent of this damage, the species of nematode involved, and possible control measures.

Seedling diseases which frequently reduce stands and the vigor of the young plants are being investigated.

Since 1941 the Office of Vegetable Crops and Diseases, United States Department of Agriculture has cooperated in the peanut investigations.

A study of the diseases of muscadine grapes, started in 1938, has shown that the Guignardia causing leaf-spot and fruit flecking of muscadines differs pathogenically from that on bunch grapes, and that at least one other specialized form of G. bidwellii occurs in this country. In like manner, a common leaf spot of muscadines, superficially resembling the Mycosphaerella personata spot on bunch grapes, is produced by an entirely different species, M. angulata. The economics of spraying muscadine vineyards for disease control has not yet been determined satisfactorily and is still under investigation.

Breeding for wilt resistance in watermelons, started in 1936, has resulted in the development of two highly resistant strains: "Georgia Wilt Resistant" and "Georgia Wilt Resistant No. 2". The former was too small to meet our present market demand, and the latter had a rind too tender for shipment. Both have been used in further crosses and the progenies are in process of reselection.

The principal objective in cantaloupe breeding is resistance to downy mildew; but genes for resistance to powdery mildew and to aphis injury became available and resistance to all three have now been combined with high quality of flesh. Yield and shipping qualities are yet to be determined.

The work on diseases of pasture plants, started June, 1949, is primarily related to a breeding program with fescue and white clover.

Numerous contributions on the physiology, life history, morphology, and systematic relationship of parasitic fungi have also come from this institution.

University of Georgia. Members of the staff of the Department of Plant Pathology have carried on some research since establishment of the department, but most of the published work should perhaps be classed as mycological. Several notable contributions on morphology and classification of Ascomycetes have been published.

Among the contributions to plant pathology may be mentioned: peanut seedling wilt, tomato seed treatment, and Helminthosporium disease of oats.

Study of the peanut seedling wilt was made in connection with a peanut disease survey made during the summer of 1931. The wilt was attributed to Fusarium martii var. phaseoli.

In the tomato seed treatment studies numerous samples of commercial tomato seed were examined and the seed-borne fungi and bacteria of pathological significance determined. Determinations were also made as to whether the organisms were internal or merely on the surface. The factors involved in disinfectant injury of the seed were also studied.

The study of Helminthosporium diseases of oats is still in progress.

Georgia Coastal Plain Experiment Station: A department of plant pathology was established October, 1947. To date, the pathologist's time has been occupied largely with cooperative testing of disease susceptibility of new varieties and strains of cotton, corn, Sudan grass, and sweet potatoes in connection with breeding projects with these crops; but research on internal cork of sweet potato has been started.

State Board of Entomology: Occasionally, workers in the State Board of Entomology have carried on investigations of plant diseases in connection with their regulatory work, such as:

1. Studies on cotton wilt by I. F. Lewis, 1906-1911. Largely testing varieties for resistance to wilt.
2. Phony disease of peach was described by D. C. Neal in 1920.
3. Study of disease-producing organisms carried on commercial tomato seed, by O. C. Boyd in 1925.
4. Entomologists are at present cooperating with the pathologists and entomologists of the U. S. Peach Disease Laboratory, Fort Valley, Georgia, in the study of phony disease of peach.

United States Department of Agriculture: Plant pathologists of the United States Department of Agriculture have obtained research data, for numerous contributions, in whole or in part, in Georgia. W. A. Orton and F. V. Rand in their publications of pecan rosette mention work at Cairo, Georgia, in 1903. W. M. Scott and T. W. Ayres worked on peach brown rot control in the J. H. Hale orchard near Ft. Valley during 1907 to 1909. The development and use of self-boiled lime sulfur was based largely on this work.

Work on peach scab was carried on at Cornelia during the summers of 1910, 1912, and 1913.

A laboratory for study of pecan diseases was established at Thomasville in 1918. In 1930, it was moved to Albany where a special laboratory and office building was constructed. Pathological work has been mostly related to pecan scab and its control.

A peach disease laboratory was established at Ft. Valley in 1921. Control of brown rot and bacterial spot were studied over a period of years. In 1923, L. M. Hutchins began study of "Phony Peach." He found it to be a virus disease; and, like many other viruses, a baffling field of research. Transmission of the disease was not easy and no natural vectors were found until recently. The work on this disease is being expanded through cooperation of pathologists and entomologists in studying the spread of the disease in nature.

In 1924, a tobacco disease laboratory was established at Tifton in cooperation with the Georgia Coastal Plain Experiment Station. At present two pathologists are employed. The field of investigation has included: downy mildew, damping-off, black shank, root-knot nematode, and southern blight. Root-knot nematode control has been most intensively studied, including studies on chemical treatment of soil and on crop rotations.

A nematology laboratory was also established at Tifton in 1935. At present two nematologists are investigating various methods of nematode (principally root-knot) control. Fumigation and other chemical applications, rotations, and cultural practices are being studied as to effectiveness and cost.

A laboratory for studying diseases of tomato and other seedling plants was established at Tifton, January 1, 1937. At present, two pathologists are employed, studying principally diseases, cultural practices, and methods of handling and shipping tomato plants.

On August 15, 1935, J. L. Weimer was located at the Georgia Experiment Station, Experiment, to study diseases of winter cover crops, principally Austrian Winter Pea and vetch. At that time Austrian Winter Pea was the most popular winter cover crop, but was frequently killed almost completely by diseases. The principal destructive diseases were, in order of importance: black stem, *Ascochyta* sp.; *Septoria* leaf and stem spot; and root rot, *Aphanomyces euteiches* Drechsler. More than 400 varieties and strains of peas were assembled and tested for resistance to these diseases, and to cold injury. No marked resistance to black stem was found; but some resistance to root rot was obtained in selections from a cross between the Austrian Winter pea and a variety known as Nitrogen pea and also between the former and a vigorous non-winter hardy pea from Puerto Rico. Selected strains from these crosses are winter hardy, are somewhat earlier than Austrian Winter and usually produce more green matter. Six of these strains are being tested for seed production in Oregon and for vegetative growth in Georgia; one appears especially promising.

The diseases of other leguminous cover crops and forage crops have been studied: kudzu, cowpea, soybean, *Chamaecrista*, *Crotalaria*, *Lespedeza*, and lupines. At present, the diseases of lupine, including seed deterioration, of the blue lupine are being investigated.

Cooperation in the cotton breeding program and in peanut investigations has been noted in discussing work of the Georgia Experiment Station.

GEORGIA AGRICULTURAL EXPERIMENT STATION

A HISTORICAL SKETCH OF DISEASES OF FOREST TREES IN GEORGIA

Julian H. Miller

A very good early description of the Georgia forest flora is to be found in "Travels of William Bartram". When this trip was made in 1773-78 the Indians still occupied much of the State and most of it was in forests. The longleaf pine was the dominant tree on the coastal plain. In the piedmont, hardwoods, chiefly giant oaks, chestnut, and hickory, predominated. Pines, present in lesser quantity, became abundant in this area only after the original forest was cut down. The mountains also were clothed with hardwoods, principally chestnut, chestnut oak and scarlet oak, with some pine, shortleaf on south slopes, and both white and Virginia pine, at the lower elevations. The Cherokee and Creek Indians cleared very little land, but when the early settlers flocked in after 1800 the picture soon changed. The rapidly formed clearings, reaching a peak about 1850, followed by accelerated soil erosion, presented another environment. On the heels of these major changes we see the rapid progress of certain tree diseases. This could be explained in part on the basis of changes in tree type and in environment, especially in the soil, and of course in large part to introductions of parasitic organisms the traveling American has inadvertently brought in. Some of these major developments in forest pathology are given below.

Phytophthora Root Disease of Chestnut and Chinquapin. Chestnuts and chinquapins were disappearing in this State long before the arrival of the present blight. The first report was probably that of Jones (1) in 1825. The late Chancellor D. C. Barrow of the University of Georgia remembered the many chestnut rail fences in the piedmont section, and that toward the latter part of the last century they vanished in this area along with the chestnut tree. Clinton (3) cited records of chestnuts dying out in the piedmont counties of Hall, Elbert, Carroll and Walton in the 20-year period prior to 1875. However, in 1907 there were still many chestnut trees left on the higher ridges, and mountaineers would come down to Athens in covered wagons loaded with apples and chestnuts. This early dying was probably due to Phytophthora cinnamomi. Proof of the relationship of the fungus with the root disease of chestnut was given by Crandall, Gravatt and Ryan (33). A description was recorded earlier by Crandall (9).

Chestnut Blight (Endothia parasitica). This disease first appeared in the Georgia mountains about 1918, and in 1920 the writer observed many dying trees with characteristic symptoms across Niels Gap in Union County and in Rabun County. A survey was made by Gravatt and Marshall (5) in 1924-25, when the blight was found in most of north Georgia. At that time isolated infection areas existed in Georgia and Tennessee, and the above writers thought the eradication of this spot infection when it was still small would have resulted in delaying the death of trees further north for many years, as the main area was still hundreds of miles north of the Georgia mountains. At the present time most of the large trees are dead, but sprouts are still coming from stumps and partially destroyed trees. These dead trees are fast being taken out for acid wood, and chestnut oak, scarlet oak, and other associated species have largely replaced the chestnut.

Twig Cankers of Asiatic Chestnuts. These cankers caused by the fungus, Cryptodiaporthe castanea, have been reported by Fowler (13) at Albany, Jasper and Savannah.

Freezing Injury to Asiatic Chestnut. Crandall (28) found such injury all over Georgia in November 1940.

Two Leafspots of Black Locust. One of these caused by Macrosporium sp. was reported by the writer (8) from a Civilian Conservation Corps project nursery at Athens in 1935. It was the first reference to the fungus in this country. Davis and Davidson (14) also found it, along with another leafspot (Fusicladium robiniae), in nurseries at Americus and Flowery Branch.

The Popcorn Disease (Sclerotinia carunculoides) of the Mulberry. This disease is confined to south Georgia, where it has long been the custom to have a grove of mulberries in the hog lot. In this respect it is of some economic importance. Jenkins and Siegler (12) report it from Ben Hill, Telfair, Randolph, Peach, Lanier, Berrien, and Jefferson Counties.

Mimosa Wilt (Fusarium perniciosum). While this recently discovered disease was first reported in Tryon, North Carolina, it was soon found in Georgia, and Hepting (17) in 1939 cited it from Monticello and LaGrange. Later Toole (23) showed it to be distributed over most of north Georgia and in one south Georgia county. The writer first noticed it in an escaped mimosa grove along the river in Clarke County in 1938, and these trees all died, even the small seedlings, within two or three years. Since then most of the campus trees at Athens have succumbed, as well as many on the city streets.

Cephalosporium Wilt of Persimmon. This disease of the native persimmon was first noticed in Georgia by the writer in 1940. Several large trees died in the Athens area. It was thought that this tree was doomed, but the disease did not spread very rapidly and now it is difficult to find an infected tree. Beattie and Crandall (16) and Crandall (15) found it chiefly in south Georgia, but did cite a few cases in northwest Georgia.

Glomerella Leafspot of Magnolia. Fowler (37) in 1947 reported a serious spotting of leaves of Magnolia grandiflora over the entire range of the tree. The causal organism is a form of Glomerella cingulata.

A Recently Discovered Elsinoe Spot on Flowering Dogwood. Dr. A. A. Bitancourt first discovered this disease of Cornus florida in Savannah in the spring of 1939. The writer later secured it from street dogwoods in Atlanta in 1947, and since then from many mountain counties near the North Carolina line as well as in Clarke County. It has been described as Elsinoe corni by Jenkins and Bitancourt (38, 39), and they cite the Georgia locations. The fact that it attacks the flowering bracts as well as the leaves and twigs makes it of much more importance than the usual Septoria leafspots. Last spring and summer the writer found it in serious proportions only in the mountains. In Athens it does not seem to be spreading to nearby trees from the first two infected plants. Other dogwoods, such as Cornus amomum and C. stricta, are apparently not susceptible.

Brooming Disease of Various Trees. A witches'-broom of virus origin was found on black locust and reported by Grant and Hartley (10) in 1938. They note that Dr. G. G. Hedgcock discovered it at Ellijay in 1914. Grant, Stout and Readey (26) stated that it was found in Georgia before 1900.

Dr. G. E. Thompson discovered a similar disease on mimosa in Clarke County in 1944.

In 1938 the writer noticed a severe case on Japanese walnuts (Juglans sieboldiana) in Clarke County. These trees were sent here by the U. S. Department of Agriculture, about 25 years ago and planted in three different locations. By 1949 all the trees were affected. Nearby black walnuts and pecans show no such symptoms.

Littleleaf of Pine. This disease probably stands next to the chestnut blight in its far-reaching effect on the forests of the State. It was first discovered and reported for Georgia by Dean D. J. Weddell at Hamilton in a letter to Dr. P. V. Siggers in 1939. It was described by Siggers and Doak (20) in 1940. The next year Toole and Buchanan (22) in a survey reported it from all of piedmont Georgia, chiefly on shortleaf pine (Pinus echinata), but also on loblolly (Pinus taeda). Hepting, Buchanan and Jackson (34) described in detail the symptomology of littleleaf. Campbell (40, 42) in 1948 discovered an association with Phytophthora cinnamomi. At this time littleleaf in Georgia is confined chiefly to the piedmont, the main habitat of shortleaf pine.

A Pine Branch Canker Associated with Atropellis tingens. Diller (31) first reported this disease from Georgia in 1943. He studied it on pine plantations in south Georgia. Later he made a State survey and found it widespread on most species of hard pine. One can see this canker commonly on the lower limbs of pines, but it apparently is not a serious factor in the growth or form of the trees.

Brown Spot Needle Blight (Septoria acicola) of Pine Seedlings. This is found chiefly on longleaf (Pinus palustris), but occurs on many hard pines, and is well distributed all over south Georgia, and occasionally in north Georgia on some slash pine (Pinus caribaea) plantings. Siggers (32) studied the effect of fires on the disease in Camden County. Hedgcock (7) in 1932 mentioned its occurrence on Pinus palustris, P. taeda and P. virginiana. However, H. W. Ravenel was the first to collect brown spot according to Siggers (32). This was at Aiken, South Carolina in 1876. This locality is near the Georgia line, so it has probably been in this State for many years.

Fusiform Rust (Cronartium fusiforme) on Pines in Nurseries. Rust developed as a serious factor in pine nurseries established by the Civilian Conservation Corps during the last decade. Once the main stem of the seedling pine was infected death followed later when the tree was in the plantation. Lamb (19) found a medium amount of infection in south Georgia and light infection in the northern part of the State. This disease is also a serious factor in some plantations, particularly in slash pine. In 1938 the disease was most serious in the nursery and the field. This coming year the disease also promises to be extremely severe.

Pitch Canker, A New Disease of Southern Pines. Hepting discovered this disease in 1945 on Pinus virginiana in North Carolina and later found a similar pitchy canker on the turpentine faces of slash pine in Georgia, and he and Roth (36) published a description. Dr. W. A. Campbell also observed this disease on the former pine in the mountains of north Georgia. The causal fungus was described and named by Hepting (43) as Fusarium lateritium f. pini in 1949.

White Pine Blight. Toole (44) reported a serious blight of white pine (*Pinus strobus*) in three north Georgia counties in 1949. The cause is unknown, but the condition has been observed for years throughout the eastern part of the United States and Canada.

Nursery Blight of Cupressus. The writer noted this blight (*Phomopsis juniperovora*) on *Cupressus sempervirens* growing in a nursery of the Horticulture Department at Athens in 1934.

Blight of Sweet Gum (Liquidambar styraciflua) on the Fort Benning Reservation. Sweet gum trees in the Fort Benning area, both on streets and in woods, have been dying from this blight. It has been described by Garren (45) but he did not determine the cause of the disease. The writer has also studied specimens of drying branches and has not been able to isolate a probable parasitic organism.

Fomes annosus Root Rot of Red Cedar. This disease is common in certain areas of the southeastern piedmont and was observed by Dr. W. A. Campbell on red cedar (*Juniperus virginiana*) in Elbert, Jackson and Morgan Counties in 1949. The fungus has also been found on old stumps of shortleaf, loblolly, and Virginia pine.

In addition to the above important diseases many papers on Georgia tree-inhabiting fungi are to be found in the literature. Ravenel (2) was probably the first to collect fungi here. Specimens from his Darien station were described by either M. J. Berkeley or M. C. Cooke at Kew Botanic Gardens.

Much later there were papers on tree rusts with Georgia locations by Hedgcock (18) and Boyce (30).

Ascomycetes have been listed or described as new by Miller (24, 25), Miller and Burton (27), or Miller and Thompson (21), and the latter (11) has reported some fungi occurring on trees.

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UNIVERSITY OF GEORGIA, ATHENS

PHYTOPATHOLOGY IN MAINE 1906-1949

Donald Folsom

Since the establishment of the Department of Plant Pathology at the University of Maine at Orono in 1906, most of the phytopathological research in Maine has been done by full-time workers because of the short growing season, the distance of crop areas from the University, and the considerable participation by members of the U. S. Department of Agriculture. Work on potato diseases has predominated because general conditions in Maine have emphasized economic research, and the potato crop has been by far the most important one.

Phytopathologists engaged continuously in research here for fourteen to 35 years each are E. S. Schultz, Donald Folsom, Reiner Bonde, the late W. J. Morse, and M. T. Hilborn. Others who have worked here for shorter periods include I. E. Melhus, L. O. Kunkel, H. A. Edson, C. E. Lewis, M. Shapovalov, G. B. Ramsey, L. O. Gratz, T. T. Ayers, Florence L. Markin, A. E. Rich, A. F. Ross, S. F. Snieszko, and M. R. Harris. Many contributions have been made to phytopathological research by geneticists, entomologists, chemists, and specialists in other sciences.

Close cooperation has been maintained by research phytopathologists with extension specialists and State seed inspection agents, both of whom have furnished new problems and data on old ones, and with visitors making plant-disease surveys. A file is maintained that includes records of all plant diseases found in Maine. With a department library, and a collection of thousands of separates and bulletins catalogued by subject with supplementary author indexes, the Department of Plant Pathology serves as a source of phytopathological information for extension specialists, State agents, teachers, students, and farmers.

POTATO DISEASES

Pioneering research on potato diseases in Maine has been concerned with late-blight epidemiology, blackleg, Rhizoctoniose, potash deficiency, boron toxicity, differentiation of mosaics, insect transmission of viruses, leafroll net necrosis, non-parasitic stem-end browning, *Verticillium* wilt, spindle tuber, tuber-unit seed plots, foundation seed, *Alternaria* tuber rot, *Botrytis* tuber rot, yield reduction by Bordeaux mixture, mahogany browning, new tuber disinfectants and foliage fungicides, and resistance to mosaics, late blight, ring rot, and leafroll. Detailed investigation has been made of the comparative value of fungicides and of the relation of insect infestations to virus epidemics. Techniques have been developed for valuable services such as foundation seed maintenance and Florida winter testing of seed stocks.

FRUIT AND VEGETABLE DISEASES

Pioneering research has been carried on in Maine on apple scab in twigs, storage apple scab, the effect of fungicides on apple trees in replicated plots, winter-hardy apple trees, new apple spray booms, fungicide control of lowbush-blueberry diseases, and resistance to cucumber scab.

CONTROL OF POTATO VIRUS DISEASES

Potato virus diseases in Maine were being studied in 1918 as physiological diseases caused directly by unfavorable climate or nutrition. Before long they were shown to be transmissible by grafting, sap transfer, and insects, and to be spread from one plant, row, or field to another. Differentiation was made between several mosaics, leafroll, spindle tuber, and other virus diseases. Surveys in the early twenties showed that there were no fields in Aroostook County free of mild mosaic in the Green Mountain variety, and that about half the plants of all varieties together were spindle-tuber. All virus diseases reduced the yield rate, and tuber quality was lowered by spindle tuber and, through net necrosis in certain varieties, by leafroll. Symptoms varied with weather and climate, and natural field spread of the viruses differed from one region to another. Soil harboring occurred only in diseased tubers. Healthy seed could be obtained from certain other more northern areas or by developing tuber lines from healthy tubers. Tuber-unit seed plots increased the effectiveness of roguing. Cloth cages kept viruses from entering healthy seed plots. Foundation seed is kept more nearly healthy by planting earlier and in larger seed plots, and by roguing by supervised trained roguers. Selection of the best stocks is made possible by a large-scale mid-winter Florida test run on 1600 800-tuber samples whose dormant period has been shortened by chemical treatment. Virus X (latent mosaic) is reduced by tuber

selection based on greenhouse tests on indicator plants. Aphid control with insecticides, though disappointing in virus control, has led to increased yields New varieties have been introduced that are resistant to mild mosaic.

UNIVERSITY OF MAINE

PLANT DISEASE INVESTIGATIONS AT THE NEW YORK STATE AGRICULTURAL EXPERIMENT STATION, CORNELL UNIVERSITY, GENEVA, NEW YORK

Otto A. Reinking

The plant disease investigations conducted at the New York State Agricultural Experiment Station at Geneva, New York, are primarily concerned with diseases affecting orchard fruits, nursery fruit stocks, small fruits, grapes and vegetable canning crops. In order to avoid undue duplication between the investigations conducted at Geneva and the Cornell Agricultural Experiment Station at Ithaca, projects under each general group of investigation are apportioned so that each station conducts those projects for which it is best suited. In orchard fruits, disease control studies are done at Geneva. A division of the virus troubles is made whereby the main determinations and host relationships are conducted at Ithaca and special studies on control are receiving attention at the Geneva Station. Cooperative projects on many phases of investigations are carried on by both institutions. Practically all small fruit and grape disease investigations are handled at Geneva. The vegetable studies at Geneva are primarily confined to the canning crops, such as peas, beans, tomatoes, beets, carrots and cabbage. Investigations on potatoes, grain crops, ornamentals, forest trees and many of the market garden and muck-grown vegetables, such as onions, lettuce and celery, are conducted at the Ithaca Station. Results of investigations conducted at Geneva are made available to the growers primarily through the extension service of Cornell University.

Progress in disease control has led to a practice of better and more economical control of our major plant diseases. The main projects deal with fungicides and their application, and the production of resistant varieties. The Geneva Station has helped in the gradual development that has led to a more practical and efficient control of many of the diseases of fruits and vegetables in its sphere of investigations.

A spray program with new fungicides takes years of development before it is safe to place into practice. Already the premature general use of certain organic sprays appears to have resulted in the reduction of fruit crops the following year. We must know what effect the new fungicides have on the trees or vegetable crops as well as on the control of a fungus before we can recommend a change. In our plant pathological investigations we are not only interested in fungicides that control disease but in those which control with the least amount of injury to the plant under consideration. The ideal fungicide is one that will control disease and at the same time increase the productivity of the plant. With the interest shown in commercial development of the many organic fungicides, attainment of this goal appears to be possible.

A review of some of the outstanding accomplishments made at the Geneva Station is presented on the following pages indicating the part the station played in the evolution of certain control practices. Short statements of the work in progress are included. Examples herein presented of progress made in the past on economic control along with the forward-looking program to still further improve on these, gives an indication of the general objectives of the program of plant disease control. These studies are being conducted with Drs. J. M. Hamilton and D. H. Palmiter on orchard fruit, Dr. A. J. Braun on small fruit, Dr. H. C. Young, Jr. on fruit nursery stock, and Drs. W. T. Schroeder, R. E. Foster and O. A. Reinking on vegetable disease control investigations.

ORCHARD FRUITS

Apple scab control is the main orchard fruit project. Our major endeavor is to obtain fungicides which will reduce the number of sprays necessary to obtain economical control, and to develop spray programs which through proper timing and the use of newer types of spray machinery will reduce the cost of spraying. The results of work started in 1930 have brought about the change from lime-sulfur to wettable sulfurs. Wettable sulfur is now the accepted basic fungicide. Those materials in the carbamate and the phenyl mercury groups appear to show most promise in the fungicide work of recent years. Data indicate that they may be used for certain applications in the spray program to reduce the number of sprays required for control of rust (*Gymnosporangium* spp.) and scab (*Venturia inaequalis*) respectively.

Field investigations have shown that some of the organic compounds cause various types of injuries to the tree, which appear to be cumulative. In some cases it even appeared that the chemicals used stopped fruit bud formation with a resultant reduction of flowering and fruiting the following year. Because of this fact, a five-year orchard spray test in which micronized

wettable sulfurs are compared with the most promising organic materials has been started. The object is to determine the possible cumulative effects of the various compounds on total fruit yield, quality, and tree growth. This forward looking program should produce results that will avoid many pitfalls in the recommendation of a new spray program.

Resistance studies on apple scab control are conducted in cooperation with the U. S. Department of Agriculture and several State experiment stations in regional tests.

Eradicant treatments for the control of apple scab in the Hudson Valley area have been shown to be economical when scab carryover is heavy. Elgetol or ammonium sulfate, plus a penetrating agent, applied to old leaves on the ground before the trees reached green tip stage were the most effective treatments. (Geneva Bulletin 714).

Cherry leaf spot (Coccomyces) investigations have resulted in a change from sulfurs to insoluble coppers. Now, under special conditions the coppers may be replaced or enhanced by the use of organics such as iron carbamates.

New means of applying fungicides as spray dusts or concentrate sprays and development of formulations for use with these newer types of applicators are being investigated. The development of satisfactory machines for the application of spray dusts and concentrate sprays holds promise for a reduction in cost of application as well as decreased spray injury.

Urea foliage sprays as a means for controlling nutrition of fruit plants and their disease relation was a development started at the Geneva Station. Application of nitrogen to the foliage of trees in combination with spray materials opened a new field in the development of quality fruit production and new ideas in control of certain diseases. There are indications that application of nitrogen to the soil apparently results in more scab than when applied to the foliage. The application of nitrogen to the foliage of the apple and pear trees at certain stages of growth may be one method of reducing ravages of the pear blight organism. Long-time tests are underway to prove these points.

Apple rust diseases are now readily controlled by the application of iron carbamates. These studies were initiated a number of years ago in the Hudson Valley and have solved the spray program for control. The ferric carbamates are specific and phenomenal in their control of rust and need not be timed so closely as was the case with sulfur sprays.

Peach leaf curl (Taphrina deformans) investigations have resulted in the development of a more flexible and economical spray program. Dinitro materials have been found to be eradicants much in the same order of lime-sulfur. They not only give excellent leaf curl control but expedite spraying when the peaches are interplanted with apples.

Brown rot of stone fruits (Monilinia) still needs much more study. Investigations indicate that the sulfur sprays will not control under all conditions. Organic fungicides are being tested. The nutritional angle in relation to susceptibility, insect control, and the proper handling of fruit at harvest time are other important phases being studied.

Investigations on increasing the resistance of the plant to fungous, bacterial, and virus infection by absorption of the toxicant into the host tissues as yet have not given uniformly good results.

Sooty blotch (Gloeodes) of pears has been satisfactorily controlled in the Hudson Valley with one application of a dinitro material like Elgetol. The same treatment has given satisfactory control of pear pyslla. One spray at a higher concentration is now being applied to control both troubles. Further studies on the control of Fabraea leaf and fruit spot are being made. The ferric carbamates show promise.

Fire blight (Erwinia amylovora) control through spraying with germicidal, nutritional and hormone-like sprays are underway. Resistant variety tests are being made in cooperation with various State and U. S. Department of Agriculture regional projects.

X-disease of peach (virus) has been satisfactorily controlled by removal of diseased chokecherries (Geneva Bulletin 704). These studies were made primarily in the Hudson Valley. Further cooperative studies have shown that the same disease is present on sour and sweet cherries. No vector has been found although studies along these lines have been enlarged. Apparently the disease is only spread from the chokecherry to the stone fruits mentioned and does not spread from tree to tree within the peach or cherry orchards. Work on the entire X-disease complex is being continued.

NURSERY FRUIT STOCKS

The development of a spray program for control of apple scab, cherry, plum, quince, and pear leaf spots, and powdery mildew on all stock is of first importance. The project is being carried out in cooperation with the Division of Entomology at Geneva in order to formulate com-

bination sprays for insect and disease control. While many of the fungicides used for mature trees may serve for certain diseases, this is not true for the control of all the troubles encountered in the nursery. The timing of both fungicide and insecticide sprays for economic control needs further study.

The cause and control of storage molds and cankers is another project conducted in cooperation with the Division of Pomology at Geneva and with certain nursery companies.

A project relative to the influence of the rootstock on the scion susceptibility to scab in apples is now receiving attention. It has been started with the cooperation of the Division of Pomology, Geneva.

A long time project on the production and maintenance of virus-free foundation stock of commercial fruit varieties for the nursery trade was inaugurated in cooperation with the Division of Pomology, Geneva, and the Department of Plant Pathology, Ithaca. It is at present confined to stone fruits, principally sour cherry, but will be gradually enlarged. A program of indexing of sour cherries and seedling root stock for freedom from virus infection was started using the present accepted methods of indexing. Further studies on the improvement of methods of detection are underway. The present method used has been adequate in pointing out sour cherry trees infected with ringspot and yellows. Whether the method presently in use is 100 percent efficient remains to be seen. Virus indexing is done both in the greenhouse and the field. An isolated block is maintained for the production of healthy budwood, the parent trees having been indexed at least twice. Blocks of diseased trees are maintained for further study of the virus troubles and for a source of the different virus diseases for use in special studies.

At present there are 16 Montmorency sour cherry trees in the isolation block which have been indexed six times without showing any evidence of virus. Buds from these trees are being used for propagation on rootstocks which are as free from virus diseases as can be obtained at present. Budwood from these 16 trees, in limited quantities, was made available to the nursery industry in the 1949 season. There are also 15 English Morello trees in the isolation block which have been indexed twice, and other varieties of both sweet and sour cherry will be added to the program.

SMALL FRUITS AND GRAPES

A revision of the spray schedules for the control of grape diseases has been a gradual, evolving process during the past nine years. The first schedules included the use of bordeaux mixture and insoluble coppers for the control of the three major diseases, i. e., black rot (Guignardia) and downy and powdery mildews (Plasmopara viticola, Uncinula necator). An injury complex due to copper sprays soon became apparent. Investigations made from 1941 to 1944, as reported on in Geneva Bulletin 712, resulted in new schedules, using reduced amounts of copper and a reduction in the number of spray applications. A reduction of from 50 to 75 percent was made in the amount of copper sulfate required to spray an acre of grapes. Through proper timing of the applications, a 40 percent saving in labor resulted from the decrease in the number of applications necessary for control. It was found that spray injury caused by the insoluble coppers could be reduced by the addition of 1 pound of lime for each 1/4 pound of actual copper in the spray mixtures. The grape spray program, however, was not considered completely satisfactory. Although the insoluble coppers with lime were shown to be less injurious to the plants, their effectiveness in controlling disease under epidemic conditions was not certain.

Tests conducted during the past five years have shown that ferric carbamate used as a spray at 1 or 2 pounds to 100 gallons of water controlled black rot better than bordeaux mixture at concentrations of 4-4-100 or 8-8-100. This material appears to cause little or no injury. In fact ferric carbamate apparently stimulates vine growth and yields of grapes, especially under certain conditions of nutrition. It was found also that early applications of this material reduced the injury from later applications of bordeaux mixture. No satisfactory substitute for copper has been found yet for the control of downy and powdery mildews.

Studies with new types of machines for applying dusts, wet-dusts, and concentrate sprays to grapes indicate that these applicators may become more satisfactory than the conventional sprayers. The use of air-blast methods makes possible more rapid applications using less fungicide per acre, resulting in lower cost per application. Furthermore, copper fungicides applied as concentrates appear to be less injurious to the vines. Progress is being made in the development of formulations of fungicides for use with these newer machines.

A revised spray program for the control of anthracnose (Elsinoë veneta) of raspberries has progressed to a point where these studies may be terminated. It has been shown that anthracnose can be economically controlled by the use of proper cultural practices along with one application

of lime-sulfur, 8 gallons liquid lime-sulfur added to 92 gallons of water. It was found that this spray is most effective if applied just as the second or third leaf is expanding from most of the buds on the fruiting canes. At this time the fungus is no longer dormant and is more susceptible to the toxic effect of the spray.

A control for spur blight of red raspberries was published during 1945 in Geneva Bulletin 711. Studies have been terminated.

The virus diseases of raspberry have been satisfactorily controlled by following the Geneva Station recommendations made in bulletins published in 1937. The methods demonstrated to be effective include planting of certified disease-free stock, plus eradication of diseased wild brambles in the vicinity of commercial plantings and roguing as disease appears in new plantings. Studies on the production of disease-resistant varieties are underway in cooperation with the Division of Pomology, Geneva.

The appearance of red-stele (Phytophthora fragariae) in strawberries in a number of commercial plantings has made it imperative to conduct more studies on this disease. Resistance studies are receiving attention with the cooperation of the Division of Pomology, Geneva.

Virus diseases, especially strawberry yellows, are becoming more acute. By indexing and isolation a stock of virus-free clones of certain of the commercially important varieties of strawberries are being obtained. Resistance studies are underway in cooperation with the Division of Pomology, Geneva.

Currant cane blight (Botryosphaeria) and Botrytis fruit rot control is receiving attention in the Hudson Valley. Both troubles are dependent upon weather conditions. Field tests on sanitation and spraying are the main avenues of attack. Special fungus studies in the laboratory and greenhouse are included. Studies on currant leaf spot control were published in 1945 in Geneva Bulletin 709.

Stunt, mummy berry, and stem canker of blueberry are under study. The nutritional phases are conducted in cooperation with the Division of Pomology, Geneva.

CANNING VEGETABLE DISEASES

The nature and control of root rots of peas is an example of a long time, extremely complex, problem. Much of value already has been learned but years of study are still needed with a well-planned, long-time rotation field experiment to give us more complete information. Investigations on the causal organisms during the seasons from 1936 through 1941 established the important root-rot organisms, their distribution, relation to some environmental factors such as seasonal variations in disease appearance and destruction, and preliminary effects of rotations and fertilization. The results were published in Geneva Technical Bulletin 264. The studies showed that Fusarium solani v. martii f. 2 and Aphanomyces euteiches were the most active organisms. The severity of each is dependent upon seasonal growing conditions. The organisms and disease were found in a wide range of soils with reactions ranging from pH 5.4 to pH 7.5. It was found that Aphanomyces euteiches may be of relatively little importance during an extremely dry season even though the soil is infested. During periods favorable to the development of this organism, especially in the early stages of growth of peas, 100 percent destruction may take place, thereby destroying the crop before it even gets underway. Early planting in well-rotated soils to bring the first growth on when the soil temperature is below an optimum for fungus growth, especially of Aphanomyces, avoids a large part of the destructive action on young, tender plants. The Fusarium is more destructive later in the season during hotter, drier weather. The effect of this organism on the host is especially marked if hot, dry weather prevails during the last two weeks of pea growth. A six-year study of fields in the Geneva Station showed that the important root-rot organims were not entirely eliminated by a three-, four- or five-year rotation. Investigations have shown that commercially profitable yields can be obtained on properly rotated and fertilized fields with early plantings.

Apparently, the virulent pea root rot Fusarium is capable of living over on beans, and possibly this characteristic serves as a means of maintaining the pathogen in an active state and capable of infecting a susceptible host following in rotation. Whether or not other plants than beans could function in this manner was not ascertained.

The above studies were amplified with a rotation plot started in 1940 to determine the effects of a fallow, legume, and non-legume rotation in comparison with continuous peas. In 1941 and 1942, disease caused a severe reduction in yield in the plots planted with continuous peas. A total loss occurred in 1943, 1944, and 1945 in the continuous pea plots. The organisms had built up on the soil to a point where it was impossible to grow peas during those years favorable for fungous development. Aphanomyces was the predominant destructive fungus, particularly

during the early part of the season, while Fusarium developed later. The severity of root rot in the other rotations during these years varied from moderate to severe with yields of from 1100 to 3300 lbs. shelled peas per acre. A summary of the yield data in 1945 showed a significant difference in yields between rotations, with the legume rotation producing greater yields than the non-legume which was equal to the fallow, and the fallow, in turn, being higher than the continuous peas. Commercial fertilizer at the rate of 600 pounds to the acre significantly increased the yield in all rotations.

In 1946, the last year of this particular rotation test, the continuous pea plots that showed failures due primarily to Aphanomyces root rot in all years since 1940 produced yields varying from 1500 to 3500 pounds of shelled peas to the acre. These were, except in one instance, almost as high as those in the other rotation plots that had yields varying from 2800 to 4000 pounds to the acre. All rotation plots with 600 pounds of a commercial fertilizer gave best yields. These data showed that root-rot infested soil can produce an excellent crop of peas, in spite of the presence of the organisms in the soil, when environmental conditions are favorable to the crop and unfavorable to the disease organisms.

To minimize variation due to seasonal conditions, which was shown to be an important factor in the development of pea root rot, a new rotation experiment was designed in cooperation with the Division of Vegetable Crops, Geneva, to study the effects of seven different vegetable canning-crop rotations on the incidence of root rot, quality and yield of peas, and on the fertility level and structure of the soil. Each rotation is for five years and five separate fields are set up so that each crop in each rotation occurs every year, thus minimizing variation due to seasonal conditions. Here again, we have another example of a carefully laid-out, long-time test which should solve further many perplexing problems connected with pea root rot.

In addition to the rotation tests on pea root-rot control, tests are underway in cooperation with the Vegetable Crops Division, Geneva, on fertilizer carriers and amendments in relation to pea root rot. Some of the various soil amendments tried in the past several years indicate that a number of materials, including gypsum and anhydrous ammonia, show promise in reducing losses.

A field study of the relation of soil type, drainage, fertilizer level, and cropping systems to the incidence of pea diseases and the effects of these various factors on the yield and quality of peas is being conducted in cooperation with the Division of Vegetable Crops, Geneva, and the Department of Agronomy, Ithaca. In these studies, an attempt is being made to correlate yield data with growing conditions found in a survey of various pea fields located in the pea-growing regions of western New York.

The development of pea varieties tolerant to heat and disease is receiving attention in cooperation with the Division of Vegetable Crops, Geneva. Results thus far from a disease standpoint have not been consistent under field conditions, owing to variable year to year environmental conditions and to the non-uniform infestation of the causal organisms. Greenhouse tests, using pure cultures of the specific pathogens in sterilized sand under controlled conditions, indicate that this technique might prove a valuable aid in a search for resistance.

A revised program for the control of diseases of tomato seedlings in the greenhouse has progressed to a point where these studies may be presented in a bulletin.

The use of growth-regulating and other materials to prevent the development of tomato ripe fruit crack molds and to hasten the rate of ripening of late-set tomato fruit by defoliation or otherwise killing the vines has been receiving attention. Indications are that the killing of the vines may reduce yield if defoliation materials are applied too early. Unless adequate disease protectant measures are adopted, it appears that any advantage gained by the use of defoliants may be offset by increased development of anthracnose. Further studies are underway.

The development of an economic spray program for the control of tomato leaf blights and fruit rots has passed through various experimental phases during the past 15 years. An excellent economic control for use under New York State conditions is now on hand. Investigations conducted in 1937 indicated that bordeaux mixture at a concentration of 4-4-50 was injurious to plants and that apparently the injury was due more to the lime than to copper. Tomatoes belong to a group of lime-sensitive plants. These findings resulted in the trial and use of red copper oxide followed by trials with various other "insoluble coppers." It was shown that particle size and the method of manufacture are closely correlated with the effectiveness of cuprous oxide. Further studies resulted in the production of yellow cuprous oxide which had a smaller particle size and proved to be a better fungicide but was more toxic to plant tissues. Since some of the fixed copper compounds gave good control without causing pronounced injury they were recommended for tomato sprays. The next step in the development of the program was the use of insoluble coppers in the first two sprays, when the plants were younger and in blossom, to

avoid lime injury and reduction of blossoms, followed by a 4-2-50 bordeaux. In 1941, gross returns from control amounted to from $13 to $54 an acre. During 1942 and 1943 the Phytophthora late blight disease, for the first time in recent years, became destructive in tomato fields. Anthracnose caused by Colletotrichum was gradually becoming more widespread. The advent of these two diseases showed that bordeaux mixture and the insoluble coppers did not produce as effective control as we desired. The copper materials were not effective in controlling anthracnose. Preliminary studies indicated that some of the new organic fungicides, especially the ferric and zinc carbamates, apparently controlled anthracnose better than copper sprays. During 1944 to 1946, further tests with a number of organic and copper fungicides were made. Early blight (Alternaria), late blight (Phytophthora), leaf mold (Cladosporium) and anthracnose (Colletotrichum) were all present in a severe form. It was found that no single fungicide tested gave maximal control of all four diseases. The fixed coppers gave good control of leaf mold, early blight and late blight, were slightly inferior to bordeaux 4-2-50 for the control of late blight. No copper fungicide tested gave adequate control of anthracnose and all were injurious, some more so than others, when used in the early applications. Many organic fungicides were tested. Best control of the four diseases was obtained with an alternate schedule of Fermate or Zerlate and various copper fungicides. No apparent injury resulted from these schedules, probably because of the fact that bordeaux was applied after August 1, after which time defloration, the principal injury factor, is not reflected in yield except during an unusually prolonged harvest season. These investigations resulted in the Zerlate-bordeaux schedule (Zerlate-Zerlate-Bordeaux-Zerlate-Bordeaux) which was found to be the most effective and efficient schedule for the control of the major diseases of tomatoes, i. e., early blight, late blight, and anthracnose. No other fungicide tested, either alone or in an alternate schedule, gave such good control. The results of these investigations were published in Bulletin No. 724 of the Geneva Station.

A comparison with airplane dust applicators and helicopters and dust applicators with ground sprays in tomato disease control indicated the latter to be more effective. Further studies, possibly with special concentrate spray equipment on aircraft, are indicated.

Investigations on the relative value of various adhesives in tomato spraying, using a newly developed print method to determine the deposition, distribution, and weathering of the fungicide pattern, indicate further benefits in a spray program. Studies are being continued.

Two years' data indicate rather definite and inherent responses of tomato varieties to the diseases late blight and early blight. It is apparent that different responses to spraying are obtained with some varieties. Apparently some varieties are more toxic to sprays than others. Further studies are underway.

The use of oil wax emulsions as sprays for the control of tomato blossom-end rot is worthy of further study. On the basis of the 1948 data increases in yield of marketable fruit were obtained which justified the added expense.

The development at the Geneva Station of a leaf print method to determine the deposition, distribution, and weathering of the fungicide pattern made it possible to determine the exact distribution of various sprays. This method was perfected by the Division of Food Science and Technology in cooperation with the Division of Plant Pathology, Geneva, for copper and Zerlate sprays or dusts and is used extensively in the tomato studies. The deposition and distribution of copper or Zerlate fungicides on the upper and lower surface of each leaf can be determined by placing the leaf between two sheets of paper impregnated with a chemical which reacted with the copper or Zerlate compounds and thereby made an imprint on the paper. The use of this method for the determination of the efficiency of operation of various spray and dust equipment has been found to be very useful and practical. Studies on the perfection of this method to include other fungicides are underway.

A project on the epidemiology and control of tomato anthracnose is receiving major attention. Far too little is known about the distribution and habits of the fungus, Colletotrichum phomoides, causing the disease. In addition to a study of the life cycle, studies include susceptibility tests on tomatoes of related species of Colletotrichum rot-producing-fungi found on other crops, tomato variety susceptibility tests, and field work involving fungicides and tomato varieties in relation to possible different reactions on tomatoes by strains of the fungus.

Breeding tomatoes for control of leaf blights, Verticillium wilt, and fruit rots is gradually assuming more importance in our vegetable disease control program. These investigations are being enlarged upon in cooperation with the Division of Vegetable Crops, Geneva.

During the past 10 to 15 years the Division of Plant Pathology, Geneva, has been one of the leaders in the development of seed treatment of canning crop vegetables. As a matter of fact the initial investigations and practical applications on vegetables were started at the Geneva Station

with the treatment of pea seeds with red copper oxide. These investigations initiated a new field of treatment for vegetable seeds to control seed decay. The program has progressed from the use of metallic fungicides to include the large field of organic fungicides. Acceptance of pea seed treatment was at first slow. In 1934 red copper was used by about 60 pea growers. In 1935 several thousand bushels of seed were treated. With the finding that graphite-treated seed along with the red copper oxide reduced friction in the seed drills to normal, the use of the fungicide in 1936 increased to 50,000 bushels of seed or enough to plant more than 10,000 acres. From then on pea seed treatment by this method was more and more extensively used, not only in New York State but in other pea-growing States. In 1936 in New York State the average increase in stand due to treatment of Surprise peas was 22 percent. Studies on its use for other varieties were underway in order to determine possible injury to susceptible varieties of peas. By 1938 some 110,000 bushels of peas were treated in the State. Studies indicated that injury resulted when fertilizer was sown with treated seed, and on acid soils. Certain drawbacks and possible injury to certain varieties of peas developed with red copper oxide, indicating the need for further study. These investigations led to the development and use of Spergon by the Geneva Station. The product was found to be superior to red copper oxide on peas. Spergon was shown to be non-toxic to practically all pea varieties, needed no lubricant and showed increased yields, even on the Alaska peas which did not respond so well with the copper treatments. By 1942 from 80 to 90 percent of the commercial acreage in New York was treated with this recently introduced seed protectant. Its use in other States was large.

The promising investigations on the control of pea seed decay, started at the Geneva Station, opened up the entire field of vegetable seed treatment. Studies at the station were enlarged upon to include the treatment of all seeds of vegetable canning crops. Tests with available new organic compounds were initiated and results of this work showed that certain vegetables responded better to particular fungicides. Studies on sweet corn, spinach, beets, carrots, and cucurbit seeds were made. The original investigations at the Geneva Station led to nation-wide cooperative tests, which resulted in unified fungicidal vegetable seed treatment recommendations. A summary of vegetable seed treatment will be presented in a bulletin now in the process of preparation.

Cabbage yellows (Fusarium oxysporum f. conglutinans) investigations started in 1937 had as their first object the testing of resistant varieties under New York conditions and to acquaint the cabbage growers in the State with the seriousness of the problem and its control. Three years' results of replicated and commercial field tests with cabbage yellows-resistant varieties of early, mid-season and late types were published in 1940 in Station Bulletin 689. This work and other publications made the growers more conscious of the trouble and brought them up to date with the latest control development. These studies indicated that resistant varieties then on the market were not entirely adequate to produce the yields and types required by the New York State cabbage growers. Need was shown for an earlier resistant kraut and market type and for resistant Danish types. Breeding for the production of such types was started and is now in progress. A number of promising strains of resistant Danish and kraut types are being developed for release.

An internal discoloration of cabbage, possibly a nutritional trouble, is receiving attention in cooperation with the Division of Vegetable Crops.

A perplexing beet root rot trouble is receiving added study. Apparently this trouble is becoming more widespread and appears to be developing into a major problem.

Carrot yellows caused by the aster yellows virus has increased in the past few years in western New York and threatens the production. Infection in fields varied from 5 to 78 percent. Investigations have been underway since 1944 in cooperation with the Division of Entomology at Geneva. Life history studies with the six-spotted leafhopper (Macrosteles divisus) indicated that control could be affected through a control of the insect. Data accumulated over the past three years on the use of DDT for yellows control showed an effective and practical method of control. These studies terminated in the publication of Geneva Bulletin 737. Further investigations are underway on methods of application with different types of sprayers.

Susceptibility studies with carrot yellows have been underway and some differences in response have been noted under field conditions. Whether this is due to leafhopper preference rather than to an inherent physiological resistance to the disease needs further study. These studies indicate that further selection for increased tolerance or resistance are warranted.

The control of insects and diseases of cucumbers and melons is receiving attention in cooperation with the Division of Entomology. These studies are primarily concerned with control of bacterial wilt and virus troubles through control of insect vectors.

Hop disease investigations have developed an adequate spray program for the control of the major diseases. Emphasis is now placed on the development of disease resistance in hops by

breeding in cooperation with the Division of Pomology at Geneva. Variety resistance tests as well as selections for resistance have produced some promising material for further studies.

NEW YORK STATE AGRICULTURAL EXPERIMENT STATION, GENEVA

PLANT PATHOLOGY AT WEST VIRGINIA UNIVERSITY: PAST AND PRESENT

PAST

C. R. Orton

The history of a department is a record of events during the life of the department, which have influenced its development. It should include personnel, its activities, administration, cooperation, finances and effects on the general welfare.

The first publication from West Virginia University dealing with plant pathology was a brief description of some common diseases in Bulletin No. 21, April 1892, by A. D. Hopkins and C. F. Millspaugh under the title, "Injurious Insects and Plant Diseases."

The earliest experimental work in the field of plant pathology at West Virginia University was conducted by F. W. Rane, Horticulturist in the Agricultural Experiment Station, on the control of early blight of the potato and potato scab. It was found that three applications of Bordeaux Mixture controlled early blight on all but the most susceptible varieties, and that barnyard manure and lime applied to the soil increased scab, while soaking the seed tubers in corrosive sublimate reduced scab. (Bulletin 38, Nov. 1894).

The systematic study of plant diseases at this Station may be said to have been initiated by J. L. Sheldon, who was Plant Pathologist and later Bacteriologist for the Station during the years 1903 to 1907. As plant pathologist in 1903, he was perhaps the first person to hold that title in the United States. Sheldon found that the anthracnose of watermelons was a serious disease in the Ohio Valley and by means of controlled experiments showed that the fungus from watermelon would infect cucumber, gourd and muskmelon, but neither squash nor pumpkin, nor wax beans. Spraying experiments with Soda-Bordeaux, Bordeaux, and ammoniacal copper carbonate, showed a decided decrease of the disease on blocks sprayed with the two Bordeaux mixtures, while plants sprayed with ammoniacal copper carbonate were not much better than the unsprayed plots. (Sheldon, J. L., Muskmelon Blight. West Virginia Agr. Exp. Sta. Circ. 2. 1903; ibid. Bull. 94, Dec. 1904, Diseases of Melons and Cucumbers, West Virginia Agr. Exp. Sta.).

Sheldon studied the ripe rot of guava, an important disease caused by Glomerella psidii, the perfect stage of which he discovered and fully described. (Bull. 104, Apr. 1906).

During Dr. Sheldon's tenure a systematic attempt was made to collect and incorporate in a herbarium the parasitic fungi of the State. The collections were all studied carefully and accurately labeled. They form the basis of the known plant diseases of West Virginia. He published three accounts of his collections ("Report on Plant Diseases of the State. West Virginia Agr. Exp. Sta. Rept. 1903-04. 67-93. 1904: A Report on Plant Diseases of the State. West Virginia Agr. Exp. Sta. Bull. 96. Jan. 1905; The Principal Plant Diseases in 1906. West Virginia Agr. Exp. Sta. Rept. 1905-06: 29-39, 1906).

Dr. Sheldon's last publication as a member of the Agricultural Experiment Station Staff appeared as Bulletin 105, June 1906, under the title "Tubercles on legumes with and without cultures." He was assisted in 1907 by Carl Hartley, a young graduate from the University of Nebraska. The following quotation from Dr. Hartley in a letter dated August 10, 1949, is interesting: "Charles E. Bessey sent me to West Virginia for my first job because of his high opinion of Sheldon as a teacher, which I can emphatically confirm."

Sheldon resigned from the Agricultural Experiment Station on June 30, 1907, when he was appointed Professor of Botany and Bacteriology in the College of Arts and Sciences. From that time until 1917, plant pathology and bacteriology were taught by Dr. Sheldon. He offered two courses, one an elementary course offered in the spring term; the other an advanced course offered throughout the year by special arrangement. Sheldon also taught, in addition to botany, three courses in bacteriology--general, agricultural and medical. In 1917 N. J. Giddings became a member of the Agricultural College faculty and offered his first course in plant pathology.

In the fall of 1908, N. J. Giddings, a graduate of the University of Vermont with a Master's degree, and, at that time, employed as Assistant Botanist of the Vermont Agricultural Experiment Station, was engaged as bacteriologist and assumed his duties at the West Virginia Agricultural Experiment Station on February 22, 1909. He was given quarters in the Northeast corner of the first floor of the old Experiment Station building. The facilities were restricted to a few test tubes, a Spencer microscope, herbarium, transfer room, and an old roll-top desk and chair.

This was a great transition from a well-equiped laboratory at Vermont, but Giddings attacked the problem with ability and enthusiasm and within a few years he secured equipment that surpassed that in the laboratories of many larger institutions.

The first assignment handed Giddings was the preparation of a station bulletin on "Diseases of Garden Crops and Their Control" which was published as Bulletin 123, May 1909. Regarding this, Giddings made the following comments: "Soon after it was published, F. C. Stewart of the Geneva, New York Station wrote me expressing his opinion of young upstarts who wrote bulletins without any real knowledge of the problems existing in the area where he was located. Stewart was right and I wrote him to that effect, although the criticism did not make me any happier." To offset this discouragement he received a very kind and encouraging letter from Professor Charles Bessey, which was deeply appreciated.

As Giddings was employed as bacteriologist, his early research in the West Virginia Agricultural Experiment Station was in that field. He was assigned projects in cooperation with other members of the staff. The first was a study of the bacteria in milk, the results of which were published under the title "Experiments in the Production of Sanitary Milk" (Atwood, Horace, and N. J. Giddings. West Virginia Agr. Exp. Sta. Bull. 134, 1911.) The second was upon the effects of high pressure on microorganisms in cooperation with B. H. Hite. This was pioneer research which resulted in the establishment of general principles upon which much of our present knowledge regarding the sterilization of food products is based. The work was published under the title, "The Effect of Pressure on Certain Microorganisms Encountered in the Preservation of Fruits and Vegetables" (B. H. Hite, N. J. Giddings and Charles E. Weakley, Jr., West Virginia Agr. Exp. Sta. Bull. 146, 1914). This work led later to the first proof that a virus could be inactivated by high pressures. In collaboration with Allard of the U. S. Department of Agriculture and with Hite, it was proved that tobacco mosaic was inactivated by pressure of 130,000 pounds and above (Giddings, N. J., H. A. Allard, and B. H. Hite, "Inactivation of the Tobacco Mosaic Virus by High Pressure." Phytopathology 9: 1919).

Giddings carried over from his Vermont experience an interest in potato blights. It is not surprising, therefore, to find that he started potato spraying in 1909 which continued for several years. His first tests were at Morgantown, followed by plots at Reedsville and Moundsville. ("Potato Spraying in 1909 and 1910. West Virginia Agr. Exp. Sta. Rept. 1909-1910: 18-22, 1910; Potato Spraying Experiments in 1911. West Virginia Agr. Exp. Sta. Rept. 1911-12: 77-78. 1912). During these experiments, he developed a three-row boom with two nozzles at each row, illustrated in the 1909-10 report, p. 21.

In the fall of 1911, C. M. Gifford, a Vermont graduate, was appointed as assistant bacteriologist in the Station but, most unfortunately, he was drowned at Christmas time while skating on the Monongahela River.

In the fall of 1911, D. C. Neal, a graduate of Mississippi College of Agriculture and Mechanic Arts, was appointed Assistant Plant Pathologist. He assisted Giddings with the spray program for the control of apple rust and other apple diseases. He resigned March 1, 1914.

An important event occurred in 1912 when plant pathology was first recognized as a department in the Agricultural Experiment Station, and Giddings' title was changed from bacteriologist to plant pathologist (W. Va. Agr. Exp. Sta. Rept. 1911-12: 54. 1912).

The year 1912 was a fruitful one for the Department. It may be called the period of national recognition. Giddings published his first two papers in Phytopathology that year--the first on "A Practical and Reliable Apparatus for Culture Work at Low Temperatures" (Phytopath. 2: 106-190. 1912). This apparatus consisted of a standard incubator superimposed upon an icebox and equipped with thermo-regulator, small electric motor, rotary pump, and suitable copper piping. It worked. The second was a short paper by Giddings and Neal on "Control of Apple Rust by Spraying" in which they demonstrated that apple rust can be controlled with Bordeaux Mixture by the accurate timing of frequent applications at the critical periods of sporidial discharge (Phytopath. 2: 258. 1912.)

About the same time, the Department of Horticulture moved from the old Experiment Station Building into a temporary building (Oglebay Annex) and Plant Pathology was permitted to expand across the halls and to use the hallway to house the herbarium cabinets.

Additional funds were made available for the employment of another staff member, and Anthony Berg, a recent graduate from the University of Wisconsin, was appointed Assistant Plant Pathologist, March 15, 1913. Giddings and Berg made an excellent team and established plant pathological work at the West Virginia Agricultural Experiment Station on a sound basis, through their studies on apple rust. This problem had been of prime importance for many years in the Shenandoah Valley. It was estimated that rust caused a loss of $75,000 in one county in 1912. Work was begun on apple rust in 1910, but a formal project on apple rust was not initiated until 1913. It was continued until after Giddings resigned in 1929. Several noteworthy contributions to our knowledge of this disease were made during that period viz - "Apple Rust" by Giddings and Berg (West Virginia Agr. Exp. Sta. Bull. 154. 1915); "New or Noteworthy Facts Concerning Apple Rust" by Giddings and Berg (Phytopath. 6: 79. 1916); and "Infection and Immunity in

Apple Rust" by Giddings (West Virginia Agr. Expt. Sta. Bull. 170, 1918), a classic study of this disease. It was Giddings' and Berg's practical demonstrations of the relation of the galls in the red cedars to the apple rust which played an important role in settling the law suits against the State for cutting the red cedars in proximity to apple orchards. Many worthy citizens in the Valley considered red cedars to be of more aesthetic value than the apple orchards. Berg also worked on rust resistance in the red cedar. He found an immune red cedar at Priest's Field in Jefferson County from which propogations by cuttings and grafts were made and distributed in other States, where it is known as "Berg's rust-resistant red cedar" (Anthony Berg. A Rust Resistant Cedar. Phytopath. 30: 876-878. 1940).

The chestnut blight was found in West Virginia about 1910, and investigations were begun in 1912 by A. B. Brooks, Forest Pathologist, employed jointly by the U. S. Department of Agriculture and the West Virginia Agricultural Experiment Station, with Giddings cooperating. Several acres of forest land were acquired by the State near Great Cacapon, on which a laboratory was established for the study of the blight. One bulletin was published by Giddings. "Chestnut Bark Disease" (West Virginia Agr. Expt. Sta. Bull. 137. 1912).

"Collar blight" became recognized as an important disease of Grimes and certain other apple varieties early in the development of the apple industry in the Shenandoah Valley. Giddings carried on a rather intensive study on the control of this disease through surgical methods and inarching which saved many trees which would have died without such treatment ("The Collar Blight of Apple Trees" by N. J. Giddings, West Virginia Dept. of Agr. Rept. 29: 15. 1913).

In 1909 and 1910 there were many reports of a serious disease of tomatoes in southern West Virginia. This problem was assigned to Berg, who proved that a strain of Phytophthora infestans was the cause. Berg's careful technique enabled him to culture the organism, prove its pathogenicity and establish its close relationship with the strain causing late blight of potatoes. The results were published under the title, "Tomato Late Blight and Its Relationship to Late Blight of Potato" (Giddings, N. J. and Anthony Berg, West Virginia Agr. Expt. Sta. Bull. 205. 1926; also Phytopath. 9: 209-211. 1919).

In 1910, Mr. D. Gold Miller, a prominent orchardist in Berkeley County, sprayed a block of York Imperial apples with Atomic sulfur, with the result that those trees were practically free from rust. This set Giddings to work on a comparison of dusting vs. spraying which continued for several years; during which time several States cooperated in comparative tests.

Three publications from the West Virginia Station resulted from this project (Giddings, N. J. Orchard Spraying versus Dusting. West Virginia Agr. Expt. Sta. Bull. 167. 1918; Giddings, N. J. Orchard Dusting versus Spraying. Jour. Econ. Ent. 14: 225-231. 1921; Giddings, N. J., Anthony Berg and E. E. Sherwood. Dusting and Spraying in the Apple Orchard. West Virginia Agr. Expt. Sta. Bull. 209. 1927.)

The cooperative study with other States and Ontario was reported and published under the title "Cooperative Dusting and Spraying Experiments in 1921", and edited by C. R. Orton as a cooperative venture under the auspices of the Crop Protection Institute. (C.P.I. Digest. 1: No. 2, 1-30, 1922). It was shown that dust fungicides were nearly as effective as sprays on peaches but not as effective as sprays on apple diseases, although dusts gave good commercial control of frog-eye leaf spot.

With the acquisition, in 1916, of farm land as a gift to the Agricultural Experiment Station from Monongalia County, the Department of Plant Pathology was assigned a tract adjacent to the Horticultural Farm. An experimental planting of apple trees for rust studies brought prompt and urgent protests which resulted in moving to a tract back of the Agronomy Farm. This area was developed as a pathologium which was actively used for experimental work until after Dr. Giddings resigned in 1929. Since then, it has been used primarily for the walnut canker and chestnut blight projects.

Potato Wart was discovered in Pennsylvania in 1918 and a year later in two localities in West Virginia in Grant and Tucker Counties, at relatively high altitudes. The scare caused by these discoveries persisted for several years, and quarantine regulations invoked at the time are still in force though the disease has not recurred for several years.

Oglebay Hall was erected in 1918, and Plant Pathology moved to the top floor of the new building along with Botany. This was a welcome change of quarters which was further improved in 1927 when Botany moved to Science Hall and Plant Pathology was given one office and the laboratory vacated by that department. Greenhouse space, which had always been a problem, was partially solved by the erection of a new greenhouse in 1920 for use by Botany and Plant Pathology.

The demand for plant pathological work was increasing and, in July 1, 1920, E. C. Sherwood, who had just completed work for the Master's degree at the University of Wisconsin, was

appointed Extension Plant Pathologist, and Assistant Plant Pathologist in the Experiment Station. In July, 1926, he gave up his work in the Experiment Station and assumed half-time duties in regulatory work with the State Department of Agriculture. This arrangement was continued until his retirement in 1949. Sherwood's methodical approach to the practical control of orchard diseases and insect pests remains a standard of excellence as attested by the fruit growers of West Virginia and neighboring States. The annual control schedule published by Sherwood from the years 1926 to the present is a standard reference for the Shenandoah fruit-belt orchardists. Current issues appear under the title "Orchard Spraying Guide". Sherwood also published numerous special Extension circulars covering the diseases and insect pests of all cultivated crops.

An important addition to the staff was made in 1922 when L. H. Leonian, fresh from his doctorate work in Kauffman's laboratory at Michigan, was appointed as Assistant Plant Pathologist. His enthusiasm, training, productivity, and esprit de corps were most valuable adjuncts in the further development of the department. His scientific contributions were numerous and covered a wide field. His notable early contributions dealt with variability in the genera Phytophthora and Fusarium. For a time, he became interested in the fungi causing human diseases, but later concentrated his efforts in a study of the physiology of fungi with V. G. Lilly, a field which proved of special interest to him and in which he made notable progress. He became Professor of Mycology in 1936 and during the war years taught general bacteriology very successfully. Unfortunately, his career was untimely terminated by cancer which caused his death June 7, 1945.

Late in the 1920's, reports of a new apple disease came in from several sections of the State. The disease resembled one which occurred in Arkansas and had been described by Hewitt of the Arkansas Agricultural Experiment Station as "measles." Mr. Berg was assigned to its study, and field work was initiated in Putnam County near Winfield, in Chester County, and in Hampshire and Mineral Counties. The disease also became serious in Illinois, and specimens were received from several other States. Berg's studies soon led to the conclusion that more than one disease was involved in the "measles complex". He succeeded in isolating a Helminthosporium from the diseased trees at Winfield, which proved actively pathogenic. He named this disease "black pox" and described the pathogen under the name H. papulosum.

Giddings obtained a leave of absence in 1916-17 for graduate study at the University of Wisconsin, from which he obtained the doctorate in 1918. He remained head of the department until June 30, 1929, when he resigned to accept a position as Senior Pathologist in the U. S. Department of Agriculture. He has been stationed at Riverside, California, since that date.

The position thus vacated was filled by C. R. Orton, a graduate of the University of Vermont, with a Master's degree from Purdue University and his doctorate from Columbia University. At that time, Orton was engaged in research on seed disinfectants at the Boyce Thompson Institute, work financed at first by The Bayer Company, Inc., and later by the Bayer-Semesan Company. He had served previously for 12 years as Plant Pathologist at the Pennsylvania Agricultural Experiment Station and as Professor of Plant Pathology in the Pennsylvania State College.

The year 1930 may be termed the beginning of the period of graduate work in the department. Two graduate assistants were appointed that year--Joseph Myers Ashcroft and Bailey Sleeth, both graduates of West Virginia University, the latter having already taken his Master's degree at the University. Sleeth completed his work and received his doctorate in June 1932. His thesis was published in Bulletin No. 257 in 1934 under the title "Fusarium niveum, the Cause of Watermelon Wilt". Ashcroft completed his Master's degree in June 1931 and his Ph.D. in June 1933. His thesis "European Canker of Black Walnut and Other Hardwoods" was published as Bulletin No. 261, 1934. Up to the present time, 20 M.S. and 20 Ph.D. degrees have been earned in the Department.

Financial stringencies hit the State in 1933 when the Legislature cut the University appropriation heavily. President Turner advocated cutting overhead administrative expenses by merging related departments. An executive order was issued to Orton and Dr. P. D. Strausbaugh to study the possibility of merging all biological work excepting medicine, in a Department of Biology. A detailed report was made to the President, suggesting that Botany, Zoology, Bacteriology, Physiology, Forestry, and Plant Pathology could be organized in one department and all be housed, so far as possible, in Science Hall. This suggestion was approved by the Board of Governors and Orton was appointed head of a new Department of Biology to be administered in the College of Agriculture and Home Economics.

This was a major operation which involved moving Plant Pathology into the basement of Science Hall which, up to that time, had been used chiefly for storage. The move was made and the entire curriculum was revised. The transfer of Botany and Zoology from the College of Arts

and Sciences into a department administered in the College of Agriculture was considered by some staff members to be a serious mistake. Administrative and personnel difficulties eventually led to the dissolution of the Department of Biology in 1936 during the residency of Dr. Boucher. The Department of Plant Pathology emerged as a Department of Plant Pathology and Forestry, with Bacteriology included. Botany and Zoology were returned as a merged department to the College of Arts and Sciences. In the separation, Genevieve Clulo was transferred to the Department of Plant Pathology.

In 1938 Forestry was made a new division of the college and bacteriology was officially recognized in the reorganized Department of Plant Pathology and Bacteriology. In this year, Orton was appointed Dean and Director, and J. G. Leach, a graduate of the University of Tennessee with a doctorate from Minnesota, and at that time Professor of Plant Pathology at Minnesota, was appointed Head of the Department. Eldor A. Marten (Ph.D. Wisconsin) was Associate Professor of Bacteriology from 1936 to 1941. He did research and published papers on soil microbiology, ring rot of potatoes, and factors influencing the toxicity of cuprous oxide. Marten was succeeded by Dr. A. R. Colmer (Ph.D. Wisconsin) who resigned in 1947. While at West Virginia, Dr. Colmer did research and published papers on the pasteurization of walnut meats and on the microbiology of acid mine waters. The work on mine water bacteria was revolutionary in nature and has contributed much to the important problem of stream pollution.

Dr. Colmer was succeeded in 1947 by Dr. H. A. Wilson (Ph.D., Iowa State College), and in 1948 an additional instructor in Bacteriology was added to the Department by the appointment of Mary Alice Ryan (M.S., West Virginia University).

Three members of the Department of Plant Pathology and Bacteriology have died in active service. Lawson M. Hill who with C. R. Orton made pioneer studies in purple-top wilt of potatoes, was appointed assistant in Plant Pathology in 1937 and died in 1939 while on leave of absence at the University of Arizona. Dr. Leonian, Professor of Mycology, who joined the staff in 1922, died in 1945 after 23 years of productive research in the physiology of the fungi. Anthony Berg, who joined the staff in 1913, died suddenly from a heart attack in 1947 after 34 years of service. He was a member of the department for a longer period of time than any other person.

PRESENT

J. G. Leach

The Department of Plant Pathology and Bacteriology is now in the College of Agriculture, Forestry and Home Economics. Its scope of responsibility includes both teaching and experiment station research in the fields of Plant Pathology, Mycology, and Agricultural Bacteriology. The Department is not responsible for teaching or research in general botany. It is limited to and includes all phases of microbiology with the exception of medical bacteriology which is handled by the Medical School. The work of the Department is about equally divided between teaching and research. All members of the staff, with one exception, do some teaching, but, with the exception of the bacteriologists who have a large enrollment in general bacteriology, the teaching loads are not excessively heavy, and the subjects taught are mostly at the graduate level.

The present staff members are listed below, with a brief statement of training experience and responsibilities.

J. G. Leach, Ph.D., Minnesota, 1922 (formerly professor of Plant Pathology, University of Minnesota). Department Head since 1938. Responsible for administration of department, research work in field of forage and pasture crops, miscellaneous diseases, and insect transmission of plant diseases. Participates in teaching Elementary Plant Pathology, Advanced Plant Pathology and Insect Transmission of Plant Diseases.

C. F. Taylor, Ph.D., Cornell 1936. Professor of Plant Pathology in charge of teaching and research in Diseases of Fruits. Came to West Virginia in 1938. Participates in teaching Elementary Plant Pathology and teaches a course in the Application of Fungicides, Insecticides and Fumigants, and one in Diseases of Fruits.

R. P. True, Ph.D., University of Pennsylvania 1934. Associate Professor of Plant Pathology (formerly Associate Plant Pathologist, Office of Forest Pathology, U. S. Department of Agriculture). Responsible for teaching and research in the field of forest pathology. Teaches a class in Forest Pathology and a class in Diseases of Ornamental Plants.

M. E. Gallegly, Ph.D., Wisconsin 1949. Assistant Professor of Plant Pathology. Responsible for research on diseases of potatoes and vegetable crops. Teaches a class in Diseases of Vegetable Crops and participates in teaching a class in Advanced Plant Pathology.

C. R. Orton, Ph.D., Columbia 1924, Professor of Plant Pathology. (Formerly of Purdue, Penn State, Head of Department of Plant Pathology, West Virginia 1929-1938, and Dean of the College of Agriculture and Director of the Agriculture Experiment Station, West Virginia University 1938-1949). Research on Phyllachora and on internal bark necrosis of apple. Teaches a course in Pathological Plant Anatomy.

Genevieve Clulo Berg, A.M., West Virginia 1929. Associate Plant Pathologist. Responsible for research on internal bark necrosis of apple and on pathological anatomy of plants.

C. F. Bishop, Ph.D., West Virginia University 1948. Extension Plant Pathologist and Entomologist. Responsible for Extension work in Plant Pathology and Entomology for all crops except orchard fruits.

______________ At the present time, there is one vacancy in the Department, caused by the retirement of E. C. Sherwood who was Extension Plant Pathologist for diseases of orchard fruits.

H. A. Wilson, Ph.D., Iowa Agricultural College 1937. Associate Professor of Bacteriology. In charge of teaching and research in general and agricultural bacteriology. Teaches courses in general bacteriology, soil microbiology, water analysis, and special topics in advanced bacteriology. Engaged in research on problems of soil bacteriology and bacteriology of mine seepage waters.

Mary Alice Ryan, M.S., West Virginia University 1948. Instructor in Bacteriology. (On leave, 1949-50, working for doctorate at Penn State). Field of interest - Dairy and Food Bacteriology.

H. L. Barnett, Ph.D., Michigan State 1937. Professor of Mycology, teaching and research in Mycology. Teaches two courses in Mycology and participates in teaching a course in the Physiology of the Fungi. (Came to West Virginia in 1945 from University of Iowa).

V. G. Lilly, Ph.D., in Chemistry, West Virginia University 1932. Professor of Physiology. Teaching and Research in the field of Physiology of the fungi. Participates in teaching a course in the Physiology of the Fungi.

In addition to the above full-time staff, there are six half-time graduate assistants in the Department. Three in plant pathology, two in physiology of fungi, and one in bacteriology.

There are seven graduate students majoring in the department, the limit of our laboratory facilities until we move into the new building.

The Department, at present, is housed in Science Hall, one of the three oldest buildings on the campus, with very inadequate space, but is scheduled to move into modern quarters in the new Biology Building now under construction, slated to be completed by September 1950. The new quarters will be modern in all respects with adequate space for teaching and research, including room for 12 to 15 graduate students. A new greenhouse for the Department is planned in connection with the new building. Sufficient greenhouse space for our present needs are available, but the houses are not modern and are not conveniently located to the new building.

Three experimental farms are available for research in field, vegetable, and forage crops. Two are within two miles of the campus, one 18 miles away. Orchard fruit research is done chiefly at University Farm, a substation located at Kearneysville in the Eastern Panhandle. For forest pathology, there is available a State-owned forest of 8,000 acres about 15 miles from the campus and State-owned forest lands in many other locations, including a University Forestry Camp in Greenbrier County. Forest Pathology work is done in close cooperation with the Forestry School which is engaged in a comprehensive Experiment Station program.

Some of the principal contributions of the Department in recent years are as follows:

1. The extensive work on the physiology of the fungi started by the late Dr. L. H. Leonian, ably assisted by Dr. Lilly, and continued since Dr. Leonian's death by Dr. Barnett and Dr. Lilly, who are now writing a text book on the Physiology of the Fungi, to be published soon by McGraw-Hill Book Company. In addition to their regular experiment station work, Drs. Lilly and Barnett are directing an extensive research program on the physiology of fungi under a contract with the U. S. Army.

2. The proof of the nature and cause of the apple disease complex known as apple measles separating the parasitic disease "black pox" from the non-parasitic "internal bark necrosis" which has been shown to be caused by manganese toxicity.

3. The experimental work on control of cherry leaf spot and the demonstration of the severe cumulative injury caused by this disease. The revised spray program based on this research has saved the cherry industry of the State.

4. Demonstration that acidity of mine seepage water is due to bacterial oxidation of sulfur rather than simple chemical oxidation as generally believed.

5. Demonstration that the red precipitation of ferric hydroxide in mine seepage water is due to, and dependent upon, bacterial action.

6. The "Dealers Contact" extension program through which the control of diseases and insect pests of the home garden was greatly facilitated. For the first time in the history of the State, the insecticides and fungicides recommended by the University are available in retail stores in practically every town in the State.

7. Demonstration of the nature, cause and method of spread of purple-top wilt of potatoes and that it could be successfully combatted by controlling the aster leaf hopper with DDT. Since the use of DDT on potatoes has become a general practice, purple-top wilt has ceased to be a disease of economic importance in West Virginia, where it was once among the most destructive diseases affecting the potato.

WEST VIRGINIA UNIVERSITY

THE PLANT DISEASE REPORTER

Issued By

THE PLANT DISEASE SURVEY

Division of Mycology and Disease Survey

BUREAU OF PLANT INDUSTRY, SOILS, AND AGRICULTURAL ENGINEERING

AGRICULTURAL RESEARCH ADMINISTRATION

UNITED STATES DEPARTMENT OF AGRICULTURE

NATION-WIDE RESULTS WITH FUNGICIDES IN 1949
FIFTH ANNUAL REPORT

Supplement 192 May 15, 1950

The Plant Disease Reporter is issued as a service to plant pathologists throughout the United States. It contains reports, summaries, observations, and comments submitted voluntarily by qualified observers. These reports often are in the form of suggestions, queries, and opinions, frequently purely tentative, offered for consideration or discussion rather than as matters of established fact. In accepting and publishing this material the Division of Mycology and Disease Survey serves merely as an informational clearing house. It does not assume responsibility for the subject matter.

PLANT DISEASE REPORTER SUPPLEMENT

Issued by

THE PLANT DISEASE SURVEY
DIVISION OF MYCOLOGY AND DISEASE SURVEY

Plant Industry Station Beltsville, Maryland

NATION-WIDE RESULTS WITH FUNGICIDES IN 1949
FIFTH ANNUAL REPORT

Compiled by
The Fungicide Committee of the American Phytopathological Society:
Sub-Committee on Testing and Results of Newer Fungicides[1]

Plant Disease Reporter
Supplement 192 May 15, 1950

TABLE OF CONTENTS

[1]Members of Sub-committee:

M. C. Goldsworthy, Division of Fruit and Vegetable Crops and Diseases, Plant Industry Station, Beltsville, Maryland.
R. W. Leukel, Division of Cereal Crops and Diseases, Plant Industry Station, Beltsville, Maryland.
M. B. Linn, Department of Horticulture, University of Illinois, Urbana, Illinois.
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P. R. Miller, Division of Mycology and Disease Survey, Plant Industry Station, Beltsville, Maryland.
E. G. Sharvelle, Department of Botany and Plant Pathology, Indiana Agricultural Experiment Station, Lafayette, Indiana.
E. E. Wilson, Division of Plant Pathology, California Agricultural Experiment Station, Davis, California.
J. D. Wilson, Department of Botany and Plant Pathology, Ohio Agricultural Experiment Station, Wooster, Ohio.

1949 SUMMARY OF RESULTS WITH FUNGICIDES

The continued response of plant pathologists in the United States and Canada has again made it possible for the sub-committee on testing and results of newer fungicides to summarize this information. The reports from 196 cooperators include results with 215 different materials on 55 different crops. Thanks are due all who cooperated.

This year's report has been delayed because of a change in committee personnel. Fortunately, however, the previous committee, under the chairmanship of J. W. Heuberger, had already done the preliminary spade-work for the 1949 summary by mailing out questionnaires to cooperators. The present committee is indebted to Dr. Heuberger and the members of his committee. The committee also appreciates the services of Dr. C. E. Cox and Dr. S. P. Doolittle who kindly summarized most of the vegetable work when drafted at the last minute.

This summary does not in any way represent final conclusions or imply recommendations of any sort. It is necessarily incomplete in scope as it summarizes only the results of the 1949 experiments that were submitted to the committee by cooperators. It has been prepared solely for the information of professional people concerned with plant disease control. It probably gives a fair indication of the current trend of results with new fungicides and also brings out some of the variations in performance met with by workers in different areas. In many cases it is difficult to explain these variations. Their occurrence, however, points to the existence of important factors influencing the effectiveness or safety of the fungicides.

The committee would appreciate any suggestions or criticisms regarding this report. There is some uncertainty regarding publication of these reports in future years due to lack of funds. Some means should be provided for financing this publication in the future.

LIST OF COOPERATORS

State or Province	Cooperators	Place[2]
ALABAMA	D. L. Gill	Spring Hill
	R. L. Self	Auburn
	Coyt Wilson	Auburn & Fairhope
	Harold E. Yates	Fairhope
ARKANSAS	E. M. Cralley	Fayetteville
	H. R. Rosen	Fayetteville
CALIFORNIA	J. G. Bald	Los Angeles
	M. Cohen	Berkeley
	W. H. English	Davis
	L. J. Klotz	Riverside
	P. A. Miller	Los Angeles
	E. E. Wilson	Davis
	C. E. Yarwood	Berkeley
	G. Zentmeyer	Riverside
COLORADO	R. R. Baker	Fort Collins
	R. W. Graham	Fort Collins
	J. H. Henderson	Fort Collins
	W. J. Henderson	Montrose
	Robert L. Skiles	Rocky Ford
	W. D. Thomas, Jr.	Fort Collins
CONNECTICUT	P. J. Anderson	Windsor
	S. Rich	New Haven
	E. M. Stoddard	New Haven
DELAWARE	D. F. Crossen	Newark, Selbyville
	J. W. Heuberger	Newark, Selbyville, & Bridgeville
	P. O. Poulos	Bridgeville
FLORIDA	W. H. Chapman	Quincy
	Fred Clark	Gainesville
	Robert A. Conover	Homestead
	R. R. Kincaid	Quincy
	S. C. Litzenberger	Gainesville
	R. O. Magie	Bredenton
	G. K. Parris	Leesburg
	G. D. Ruehle	Homestead
	G. R. Townsend	Belle Glade
GEORGIA	J. R. Cole	Albany
	F. F. Cowart	Experiment

State or Province	Cooperators	Place
(Georgia)	John G. Gaines	Tifton
	U. R. Gore	Experiment
	E. F. Savage	Experiment
HAWAII	J. W. Hendrix	Maui
	H. Murakiski	Kokohead, Oahu
IDAHO	Harland Stevens	Aberdeen
	R. D. Watson	Moscow
ILLINOIS	Wayne Bever	Urbana
	J. C. Carter	Urbana
	R. G. Emge	Urbana
	J. L. Forsberg	Kankakee County
	J. W. Gerdeman	Urbana
	Benjamin Koehler	Urbana
	M. B. Linn	Urbana
	Dwight Powell	Urbana
INDIANA	R. M. Caldwell	Lafayette
	D. E. Likes	Lafayette
	Eric G. Sharvelle	Lafayette
	J. R. Shay	Bridgeport
IOWA	H. L. Lantz	Ames
	C. S. Reddy	Ames
KANSAS	E. Abmeyer	Walthena
	E. D. Hansing	Manhattan
KENTUCKY	D. A. Reid	Lexington
LOUISIANA	J. G. Atkins, Jr.	Crowley, Hammond
	Paul Bouchereau	Crowley
	N. E. Jodon	Crowley
	E. C. Tims	Baton Rouge
MAINE	M. T. Hilborn	Monmouth
MARYLAND	C. E. Cox	College Park
	John C. Dunegan	Beltsville
	M. C. Goldsworthy	Beltsville
	W. F. Jeffers	College Park
	R. W. Leukel	Beltsville
	W. D. McClellan	Beltsville
	H. A. Rodenhiser	Beltsville
	J. W. Taylor	Beltsville
	R. A. Wilson	Beltsville

State or province	Cooperators	Place
MASSACHUSETTS	Geoffrey Cornish	Amherst
	E. F. Guba	Waltham
MICHIGAN	J. H. Muncie	Lake City
	Ray Nelson	East Lansing
	W. Toenjes	Grand Rapids
	John R. Vaughn	East Lansing
	Donald J. de Zeeuw	East Lansing
MINNESOTA	A. D. Baskin	Crookston
	T. M. McCall	Crookston
	M. B. Moore	St. Paul
	H. D. Thurston	Crookston
MISSOURI	H. G. Swartwout	Columbia
MONTANA	Francis H. McNeal	Bozeman
NEW HAMPSHIRE	M. C. Richards	Durham
NEW JERSEY	J. C. Campbell	Cranbury
	R. H. Daines	Morristown
	B. H. Davis	New Brunswick
	Spencer H. Davis	New Brunswick
	John C. Dunegan	Hammonton
	M. C. Goldsworthy	Hammonton
	C. M. Haenseler	New Brunswick
	J. M. Horn	Hammonton
	R. A. Wilson	Hammonton
NEW YORK	A. Braun	Geneva
	C. A. Davis, Jr.	Ithaca
	A. W. Dimock	Ithaca
	C. H. Ford	Farmingdale
	A. A. Foster	Farmingdale
	J. M. Hamilton	Geneva
	J. B. Harry	Yonkers
	S. E. A. McCallan	Yonkers
	L. M. Massey	Ithaca
	A. G. Newhall	Ithaca, Elba
	D. H. Palmiter	Poughkeepsie
	C. A. Reinking	Geneva
	W. T. Schroeter	Geneva
	D. M. Yoder	Ithaca
NORTH CAROLINA	C. N. Clayton	Raleigh
	John C. Dunegan	Eagle Springs

State or Province	Cooperators	Place
(North Carolina)	M. C. Goldsworthy	Eagle Springs
	F. A. Haasis	Wilmington
	T. T. Hebert	Raleigh
	J. M. Horn	Eagle Springs
	S. G. Lehman	Raleigh
	G. B. Lucas	Oxford
	E. L. Moore	Oxford
	R. A. Wilson	Eagle Springs
NORTH DAKOTA	W. E. Brentzel	Fargo
	W. G. Hoyman	Northwood
OHIO	H. A. Runnels	Wooster
	J. D. Wilson	Wooster, Marietta, Willard
	H. F. Winters	Wooster
	H. C. Young	Wooster
OREGON	B. F. Dana	Corvallis
	J. R. Kienholz	Hood River
	P. W. Miller	Corvallis
	A. P. Steenland	Corvallis
	E. K. Vaughan	Corvallis
PENNSYLVANIA	W. G. Chandler	State College
	F. H. Lewis	Arendtsville
	R. M. Means	Philadelphia
	H. W. Thurston, Jr.	State College
RHODE ISLAND	F. L. Howard	Kingston
	John B. Rowell	Kingston
SOUTH CAROLINA	C. H. Arndt	Clemson
	Robert Aycock	Blackville
	John C. Dunegan	Johnston
	W. M. Epps	Charleston
	H. H. Foster	Gramling
	M. C. Goldsworthy	Johnston
	T. W. Graham	Florence
	J. M. Horn	Leesville
	R. A. Wilson	Leesville
SOUTH DAKOTA	C. M. Nagel	Brookings
TENNESSEE	E. L. Felix	Knoxville
TEXAS	A. A. Dunlap	College Station
	J. R. Quinby	Chillicothe

State or Province	Cooperators	Place
(Texas)	J. C. Stevens	Chillicothe
	E. C. Tullis	Beaumont
	P. A. Young	Jacksonville
VERMONT	T. Sproston	Bennington
VIRGINIA	A. B. Groves	Winchester
	R. G. Henderson	Blacksburg
	T. J. Nugent	Norfolk
	S. A. Wingard	Blacksburg
WASHINGTON	M. W. Carstens	Mt. Vernon
	C. J. Gould	Puyallup
	S. C. Holton	Pullman
	F. Johnson	Puyallup
	J. R. Kienholz	Yakima
	V. L. Miller	Puyallup
	A. E. Rich	Grandview
	H. S. Schaad	Grandview
	R. Sprague	Wenatchee
	C. M. Wright	Walla Walla
	Wm. D. Yerkes	Walla Walla
WEST VIRGINIA	C. F. Taylor	Kearneysville
WISCONSIN	D. J. Hagedorn	Madison
	Paul E. Hoppe	Madison
	G. W. Keitt	Sturgeon Bay
	J. D. Moore	Sturgeon Bay
	O. J. Noer	Madison
	R. G. Shands	Madison
CANADA		
BRITISH COLUMBIA	D. L. McIntosh	Summerland
	H. R. McLarty	Summerland
	G. R. Thorpe	Creston Valley
	M. P. D. Trumpour	Salmon Arm
	M. F. Welsh	Creston Valley
	J. M. Wilks	Creston Valley
MANITOBA	J. E. Machacek	Fort Garry
NOVA SCOTIA	K. A. Harrison	Kentville
	J. R. Hockey	Kentville
	R. G. Ross	Kentville

State or Province	Cooperators	Place[2]
(Canada)		
ONTARIO	J. H. Boyce	Ottawa
	G. C. Chamberlain	St. Catherines
	J. K. Richardson	St. Catherines
	S. A. Simmons	Guelph
	A. J. Skolko	Ottawa
	M. D. Sutton	Ottawa
PRINCE EDWARD ISLAND	L. C. Callbeck	Charlottetown
SASKATCHEWAN	R. C. Russell	Saskatoon

[2] In most cases, place where work was done.

SOURCES OF CHEMICALS TESTED

Agro-Chemie	Velperweg 28 Arnhem, Holland
Arkansas Fertilizer Company	Little Rock, Arkansas
Battelle Memorial Institute	Columbus, Ohio
F. W. Berk & Company, Inc.	Wood-Ridge, New Jersey
Boots Pure Drug Co., Ltd.	Station Street, Nottingham, England
California Spray Chemical Corp.	Elizabeth, New Jersey
Calumet and Hecla Min. Co.	Pittsburgh, Pa.
Canadian Industries, Ltd.	Agricultural Chemicals Division Box 10, Montreal, Canada
Carbide and Carbon Chemical Corp.	30 East 42nd Street New York 17, New York
Central Chemical Corp.	Hagerstown, Maryland
Chipman Chemical Co.	Bound Brook, New Jersey
Clorox Chemical Co.	850 42nd Avenue, Oakland 1, Calif.
W. D. Cleary Corp.	314 Cleveland Avenue New Brunswick, New Jersey
Corona Chemical Company	Milwaukee, Wisconsin
Delmar Chemicals, Ltd.	Lashine, Quebec, Canada
Doggett-Pfeil Company	Springfield, New Jersey
Dominion Rubber Company	Metcalf Street Guelph, Ontario, Canada
Dow Chemical Company	Midland, Michigan
E. I. Du Pont de Nemours & Co.	DuPont Building, Wilmington, Delaware
Eastern Chemical Corp.	Crozet, Virginia
Esso Standard Oil Company	378 Stuart Street, Boston 17, Mass.

Flower Food, Inc.	P. O. Box 106, Maywood, Illinois
French Dyestuffs Ltd.	Hamilton, Ontario, Canada
Fuller System, Inc.	Woburn, Massachusetts
Gallowhur Chemical Corp.	801 Second Avenue New York 17, New York
Geigy Co., Inc.	89-91 Barclay Street, New York 8, N. Y.
General Chemical Co.	40 Rector Street, New York 6, N. Y.
Givaudan-Delawanna, Inc.	330 W. 42nd Street, New York 18, N. Y.
B. F. Goodrich Chemical Co.	324 Rose Building, Cleveland 15, Ohio
Green Cross Insecticides	2875 Centre Street, Montreal, Quebec
Imperial Chemical Industries, Ltd.	Hexagon House, Blackley Manchester, England
Innis, Speiden & Company	117 Liberty Street, New York 6, N. Y.
Jackson & Perkins	Newark, New York
Mallinckrodt Chemical Works	2nd and Mallinckrodt Streets St. Louis, Missouri
Merck and Co., Inc.	Rahway, New Jersey
Micronizer Process Co.	Moorestown, New Jersey
Monsanto Chemical Company	1700 South 2nd Street St. Louis 4, Missouri
New Jersey Zinc Co.	160 Front Street, New York 7, N. Y.
Niagara Sprayer and Chemical Co.	Middleport, New York
Onyx Oil and Chemical Co.	15 Exchange Place, Jersey City 2, N. J.
Panogen, Inc.	117 Hudson Street, New York, N. Y.
Parsons Chemical Works	Grand Lodge, Michigan
Pennsylvania Salt Manufacturing Co., Inc.	1000 Widener Bldg. Philadelphia 7, Pa.
Phelps-Dodge Refining Corp.	40 Wall Street New York, N. Y.

Plant Products Co.	Eatondale Avenue Blue Point, L. I., New York
John Powell & Co., Inc.	One Park Avenue, New York 16, N. Y.
R. J. Prentiss and Co.	80 John Street, New York, N. Y.
H. H. Robertson & Co.	Farmers Bank Bldg., Pittsburgh, Pa.
H. P. Rossiger and Co., Inc.	55 Vandam Street, New York 13, N. Y.
Rohm and Haas Co.	222 W. Washington Square Philadelphia 5, Pennsylvania
Shell Chemical Corp.	100 Bush St., San Francisco 6, Calif. or 50 W. 50th St., New York 20, N. Y.
Sherwin-Williams Co.	101 Prospect Avenue, NW Cleveland, Ohio
Standard Agricultural Chemicals, Inc.	1308 Adams Street Hoboken, New Jersey
Standard Oil Co. of Indiana	910 South Michigan Avenue Chicago 80, Illinois
Stauffer Chemical Co.	420 Lexington Avenue, New York 17, N. Y. or 626 California St., San Francisco 8, Calif.
Tennessee Copper Co.	900 Roosevelt Highway College Park, Georgia
Texas Phenothiazine Co.	Fort Worth, Texas
The Natriphene Co.	424 Book Bldg., Detroit 26, Michigan
United States Rubber Company	Naugatuck Chemical Division 1230 Sixth Avenue, New York 20, N. Y.
Upjohn Company	Kalamazoo, Michigan
R. T. Vanderbilt Co., Inc.	230 Park Avenue, New York 17, N. Y.
Winthrop Chemical Company, Inc.	1450 Broadway, New York 18, N. Y.
Woolfolk Chemical Company	Fort Valley, Georgia

FUNGICIDES USED IN 1949

Trade Name	Active Principle	Source
Actidione	cycloheximide	Upjohn Company
Agrosan	1.5% phenyl mercury acetate + 0.5% ethyl mercury chloride	Imperial Chemicals
Alltox-K Dust No.10-63	10% toxaphene with 6 3% copper	California Spray Chemical
Ammoniacal copper carbonate	ammoniacal copper carbonate	Homemade
Anti carie	48% hexachlorobenzene	French Dyestuffs
Apple coposil	copper silicate-zinc combination	California Spray Chemical
Arasan	50% thiram	DuPont
Arasan SF	75% thiram	DuPont
Arathane WP-25	dinitrocapryl crotonate	Rohm & Haas
Aretan	methoxy ethyl mercury chloride + alkali	Agro-Chemie
Basi-Cop	neutral insoluble copper	Sherwin-Williams
Battelle Copper Fungicide	50% metallic copper paste	Battelle Institute
Benesan	0.15% ethyl mercury chloride + 0.85% phenyl mercury acetate + 20% benzene hexachloride	Canadian Industries
Bioquin 1	copper 8-quinolinolate	Monsanto
Bismuth subsalicylate	bismuth subsalicylate	Various
Bloomocide	alkyl dimethyl benzyl ammonium chloride	Flower Food, Inc.
Bordeaux mixture	basic copper sulfates	Homemade
Bouisol	copper oxychloride in white oil emulsion	Boots Pure Drug Co.
Cadminate	organic cadmium compound	Mallinckrodt
Calcium chloride	calcium chloride	Various
Calochlor	mercurous chloride and mercuric bichloride	Mallinckrodt
Calogreen	mercuric chloride	Mallinckrodt
Carbide and Carbon 224	zinc mercury chromate	Carbide and Carbon
Carbide and Carbon 531	chromate complex	Carbide and Carbon
Carbide and Carbon 5379	ethylene bisdithiocarbamate derivative	Carbide and Carbon
Carbide and Carbon 640	copper zinc chromate complex	Carbide and Carbon
Ceresan, 2%	ethyl mercury chloride	DuPont
Ceresan M	ethyl mercury p-toluene sulfonanilide	DuPont

Trade Name	Active Principle	Source
Ceresan, New Improved	ethyl mercury phosphate	DuPont
Chlordane	chlordane	Various
Chlorax dry	sodium chlorate-pentaborate mixture	Chipman Chemical Co.
Chlorax liquid	sodium chlorate-metaborate mixture	Chipman Chemical Co.
Chromate complex A	copper-zinc chromates	Penna. Salt Mfg. Co.
Chloropicrin	chloropicrin	Various
Clorox	sodium hypochloride solution	Chlorox Chemical Co.
C.O.C.S.	basic copper oxychloride and sulfates	Niagara Sprayer
Colloidal copper-white oil emulsion	3% copper, 63% petroleum oil	Boots Pure Drug Co.
Compound A	copper oxychlorides	DuPont
Cop-O-Zink	tribasic copper sulfate + zinc sulfate	Tennessee Copper Co.
Copper A	copper oxychlorides	DuPont
Copper O	copper 8-quinolinate	Monsanto
Coppercarb	20% copper as copper carbonate	Corona Chemical
Copper oxide	copper oxide	Various
Copper 054	copper gamma chloro aceto acetanilide	Delmar Chemicals
Copper sulfate	copper sulfate	Various
Copper salt of TMTD	copper salt of thiram	Geigy
CP 2271	copper compound	Monsanto
CR 305	bis (2 hydroxy-5 chlorophenyl) sulfide	Rohm & Haas
CR 2139	not known	Rohm & Haas
CR 2228	not known	Rohm & Haas
CR 2256	not known	Rohm & Haas
CR 2320	not known	Rohm & Haas
Crag 169	copper zinc chromates	Carbide and Carbon
Crag 341-B	mixed glyoxalidines	Carbide and Carbon
Crag 341-C (Fruit)	mixed glyoxalidines	Carbide and Carbon
Crag 341-SC	mixed glyoxalidines from pure stearic acid	Carbide and Carbon
Crag 531	calcium-zinc-copper-cadmium chromates	Carbide and Carbon
Crag 640	copper-zinc-chromates	Carbide and Carbon
Crag 658	copper-zinc-chromates	Carbide and Carbon
Cuprocide, yellow	yellow-cuprous oxide	Rohm & Haas
Cuprous oxide	red cuprous oxide	Calumet & Hecla Mining Co.

Trade Name	Active Principle	Source
Cuprous powder # 3005	cuprous oxide powder	H. H. Robertson Co.
Cu-26	basic copper zeolites	Tennessee Copper Co.
D-D	dichloropropene-dichloropropane	Shell Chemical Co.
Delmo-Z	stabilized zinc hydroxide	California Spray Chemical
Dithane D-14	disodium ethylene bis dithiocarbamate	Rohm & Haas
Dithane-cadmium	cadmium ethylene bis dithiocarbamate	Rohm & Haas
Dithane-calcium	calcium ethylene bis dithiocarbamate	Rohm & Haas
Dithane-ferric	ferric ethylene bis dithiocarbamate	Rohm & Haas
Dithane-magnesium	magnesium ethylene bis dithiocarbamate	Rohm & Haas
Dithane-manganese	manganese ethylene bis dithiocarbamate	Rohm & Haas
Dithane Z-78	zinc ethylene bis dithiocarbamate	Rohm & Haas
Dimetacresyltrichloroethane	dimetacresyltrichloroethane	
Dow F-800	50% trichlorophenyl monochloro acetate	Dow
Dow 9B	zinc trichlorophenate	Dow
Dow W-40	ethylene dibromide	Dow
Dowicide B	sodium trichlorophenate	Dow
DuPont Garden Dust	5.2% zineb + 5% methoxychlor + rotenone	DuPont
DuPont Rose Dust	Fermate-sulfur mixture	DuPont
Dry lime sulfur	calcium polysulfides	Sherwin-Williams
Elgetol	sodium dinitro-ortho-cresolate	Standard Agricultural Chemical Co.
Everett flotation sulfur	by-product sulfur	
Fac-S	ferric dimethyl dithiocarbamate cyclohexylamine	Goodrich Chemical Co.
Fermate	ferric dimethyl dithiocarbamate	DuPont
Flotation sulfur	by-product sulfur	Various
Flo-sol sulfur paste	by-product sulfur	Central Chemical Co.
Flotox	sulfur	California Spray Chemical
Formaldehyde	formaldehyde	Various
Fulex B	emulsion containing 33% copper 8-quinolinolate	Fuller System Inc.

Trade Name	Active Principle	Source
G-4	dihydroxydichlorodiphenylmethane	Givaudan-Delawanna
Gallicide	phenyl mercury monoethanol ammonium acetate	Gallowhur
G.C. 308	copper nitrodithioacetate	General Chemical Co.
G.C. 629	zinc nitrodithioacetate	General Chemical Co.
G.C. 1124	thiocyanate (dinitrophenyl)	General Chemical Co.
G.C. 1189	chlorinated hydrocarbon	General Chemical Co.
Goodrite Z.A.C.	ziram cyclohexylamine complex	Goodrich Chemical Co.
Goodrite Z.I.P.	ziram cyclohexylamine p.e.p.s.	Goodrich Chemical Co.
Granosan 2%	ethyl mercury chloride	DuPont
H-258-A	organic cadmium	Merck and Co.
Iscobrome D	ethylene dibromide	Innis, Speiden & Co.
Isothan Q 15	lauryl isoquinolinium bromide	Onyx Chemical Co.
J. & P. Rose Spray	30% Fermate, 20% DDT, 10% sulfur	Jackson and Perkins
Karbam Black	ferbam	Sherwin-Williams
KF 467	bi-(ethyl mercuric) perthiocyanate	Coppers Co.
Kolodust	bentonite fused with sulfur	Niagara Sprayer
Kolofog	bentonite fused with sulfur	Niagara Sprayer
Kolozinc	sulfur-zinc complex	Niagara Sprayer
Koppers Flotation Sulfur paste	by-product sulfur	California Spray Chemical
Larvacide	chloropicrin	Innis, Speiden & Co.
L-224	zinc-mercury-chromate	Carbide and Carbon
Leytosan	7.2% phenyl mercury urea	F. W. Berk
Lime-sulfur	calcium polysulfides	Various
Lindane	gamma isome of benzene hexachloride	Various
Lysol	50% tar acids and soaps	Various
Magnesium ethylene bis dithiocarbamate	magnesium ethylene bis dithiocarbamate	DuPont

Trade Name	Active Principle	Source
Magnetic sulfur "70"	sulfur paste	Stauffer Chemical Co.
Manganese ethylene bis dithiocarbamate	manganese ethylene bis dithiocarbamate	DuPont
Mercan	5% para amino phenyl mercuric acetate	John Powell and Co.
Merck H 258 T	organic cadmium compound	Merck & Co.
Mercuran	methoxy ethyl mercuric acetate	Delmar Chemicals
Mercuric chloride	mercuric chloride	Various
Mersolite 8	phenyl mercuric acetate	F. W. Berk
Mersolite P	2% phenyl mercuric acetate in Bentonite	F. W. Berk
Methasan	ziram	Monsanto
Merthon 642	mercury complex with organic phosphates	Eastern Chemical Corp.
Methoxychlor	methoxychlor	Various
Micronized sulfur	finely ground sulfur	Micronizer Process Co.
Microsul	finely ground sulfur	Central Chemical Co.
Mike sulfur	finely ground sulfur	Dow Chemical Co.
MTH	75% nitroso phthalimidine	Dominion Rubber Co.
Natriphene	sodium 2-hydroxydiphenyl	The Natriphene Co.
Niagara carbamate	ferbam	Niagara Sprayer
N-Nitroso phthalimidine	N-nitroso phthalimidine	U. S. Rubber Co.
No. 5400	sodium dimethyl dithiocarbamate + SCl_2	Delmar Chemicals
Nu-leaf	ferbam	Niagara Sprayer
Nu-Z	zinc oxysulfate (55% zinc)	Tennessee Copper Co.
N-Cl_3	nitrogen trichloride	Various
Parathion	parathion	Various
Panogen-8	1.2% methyl mercury dicyan diamide in glycol and alcohol	Par _en, Inc.
Panogen-14	2.1% methyl mercury dicayan diamide in oil	Panogen, Inc.
Parsons Seed Saver	quarternary ammonium compound + mercury	Parson Chemicals
Parzate	zineb	DuPont
Peach Pan	zinc-sulfur-lead arsenate complex	Woolfolk Chemical Co.
Penn 492		Penna. Salt Mfg. Co.

Trade Name	Active Principle	Source
Perenox	copper oxychloride	Canadian Industries
Phelps Dodge IP 1-50	48-50% metallic copper	Phelps Dodge
Phygon	2, 3-dichloro-1, 4-naphthoquinone	U. S. Rubber
Piperonyl cyclonene	piperonyl cyclonene	Texas Phenothiazine Co.
PMAS	phenyl mercury complex	W. A. Cleary Corp.
Polysulfide compound	sodium polysulfide and sodium thiosulfate	Niagara Sprayer
Propylene oxide	propylene oxide	Various
Puratized Agricultural Spray	phenyl mercury triethanol ammonium lactate	Gallowhur
Puratized Apple Spray	phenyl mercury monoethanol ammonium acetate	Gallowhur
Puratized 806	phenyl mercury formamide	Gallowhur
Puraturf	phenyl mercury triethanol ammonium lactate	Gallowhur
Puraturf G-G	organic cadmium-mercury complex	Gallowhur
Puraturf 177	p-amino phenyl cadmium dilactate complex	Gallowhur
R-118 A	4% ethyl mercury isothio carbamide	Green Cross Insecticides
Rix	calcium polysulfides and polyethylene glycol monoisooctylphenyl ether	California Spray Chemical
Robertson's Copper Fungicide	cuprous oxide	H. H. Robertson Co.
Ro-Cop	0.75% rotenone, 5% copper	Doggett-Pfeil
Rogers C-D Tomato Dust	6% copper with 5% DDT	Texas Phenothiazine Co.
Roccal	alkyl dimethyl benzyl ammonium chloride	Winthrop Chemical Co.
Rosinamine-D-silver nitrate	rosinamine-D silver nitrate	
Rosin lime-sulfur	rosin and lime-sulfur	Homemade
Seedox	50% 2, 4, 5-trichlorophenyl acetate	R. J. Prentiss
Semesan	30% hydroxymercurichlorophenol	DuPont
Semesan Bel	12% hydroxymercurinitrophenol, 3.2% hydroxymercurichlorophenol	DuPont
Spergon	tetrachloro-parabenzoquinone	U. S. Rubber
Spergon W	tetrachloro-parabenzoquinone	U. S. Rubber
Spraycop	34% metallic copper	General Chemicals
SR 406	N-trichloromethyl thio-tetrahydrophthalimide	Esso Standard Oil Co.
Stanofide	dimethyl dialkyl ammonium bromide in alcoholic base	Standard Oil of Indiana

Trade Name	Active Principle	Source
Sulfasan	xanthogen disulfide	Monsanto
Sulforon X	wettable sulfur	DuPont
Sulfur dust	finely ground 325 mesh sulfur	Various
Sulfur-lead arsenate	90 parts dusting sulfur: 10 parts lead	Various
Sulfur wettable	wettable sulfur	Various
S.W. XP41A	xanthogen disulfide	Sherwin Williams
Tag HL 331	phenyl mercury acetate	California Spray Chemical
Tennessee 26	basic copper zeolites	Tennessee Copper Co.
Tennessee 34	basic copper zeolites	Tennessee Copper Co.
Tennessee Mixture No. 1	36% Cu, 7.6% Mn, 4.5% Zn	Tennessee Copper Co.
TEPP	tetraethyl pyrophosphate	Various
Teramine	quarternary ammonium compound	Canadian Industries
Tersan	Thiram	DuPont
Thionate "19"	ferbam	DuPont
Thiourea	thiourea	Various
Toxaphene	toxaphene	Various
Tribasic copper sulfate	copper basic sulfates	Tennessee Copper Co.
Vancide 30-W	zinc salt of 5 chloro-2 mercaptobenzothiazole	R. T. Vanderbilt & Co.
Vancide 38-W		R. T. Vanderbilt & Co.
White Diamond 63 X Tomato dust	6.25% copper from tribasic copper sulfate and 13.75% calcium arsenate	Arkansas Fertilizer Co.
Z.A.C.	ziram cyclohexylamine complex	Goodrich Chemical Co.
Zerlate	ziram	DuPont
Zinc-lime-sulfur mix	basic zinc sulfates and sulfur	Various
Zinc lime	zinc sulfate + hydrated lime	Various
Zinc oxide	zinc oxide	New Jersey Zinc Co.
Zinc sulfide	zinc sulfide	New Jersey Zinc Co.
Zinc basic sulfate (ME.2287)	zinc sulfate neutral	Niagara Sprayer

Trade Name	Active Principle	Source
Zinc lime-hydrated (ME. 2433)	zinc basic sulfates alkaline	Niagara Sprayer
Z.I.P.	ziram cyclohexylamino p.e.p.s.	Goodrich Chemical Co.
36L	nitrosopyrazole	U. S. Rubber Co.
549 C-dust	0.9% parathion, 10% Fermate, 3% Bioquin 1	Plant Products Co.
549 C-spray	4% parathion, 30% Fermate, 10% Bioquin 1	Plant Products Co
829	modified form of Crag 658	Carbide and Carbon

RESULTS WITH FRUIT DISEASES

APPLES

Reports were received from British Columbia, California, Colorado, Connecticut, Delaware, Illinois, Indiana, Kansas, Maine, Maryland, Massachusetts, Michigan, Missouri, New Hampshire, New Jersey, New York, North Carolina, Nova Scotia, Ohio, Ontario, Oregon, Pennsylvania, Rhode Island, Virginia, West Virginia, Washington, and Wisconsin.

SCAB

Information gathered from the submitted reports and from other sources indicated that the apple scab problem was most severe in the South Atlantic States of Delaware, Maryland, New Jersey, Pennsylvania, Virginia, and West Virginia. In this region summer drought curtailed late infection in Delaware and Pennsylvania. In the northern tier of States and also in Canada and in North Carolina apparently, in general, scab was not acute during the blossom period and presented no particular problem of control. This was also true of the Far West where scab was difficult to control during the previous season. In general the environmental conditions surrounding most of the tests this season were not effective in bringing out the differences between the spray materials used.

Fermate, Phygon XL, Crag apple fungicide 341C, Tag HL 331, Cr. 305, Puratized Agricultural Spray, Puratized Apple Spray, wettable sulfurs (all kinds) and liquid lime-sulfur were used most frequently in the tests. Arathane W and E, Puratized 806, Merthon 642, manganese ethylene bis dithiocarbamate, Hecla copper oxide, Goodrite Z.I.P. and Z.A.C., Merck H 258 A, Cop-O-Zink, Cr. 2139, 2228, 2256, 2330, Stanofide, Bioquin 1, Apple Coposil, Phygon dust, Actidione, and S.R. 406 were included in one or another test at the different stations.

Split schedules were used quite commonly, apparently for the purpose of alleviating the phytotoxic propensities of some of the chemicals especially where the mercury compounds were used in the early sprays. The mercury compounds were usually carried up to and including the first cover and were followed by Crag apple fungicide 341C, Fermate, or some form of wettable sulfur, or even mixtures of Fermate and sulfur. Lime sulfur was usually followed by Fermate and wettable or flotation types of sulfur, Phygon was followed by Fermate in one case, while Crag apple fungicide 341C and Fermate were followed by wettable sulfur in several cases.

Combinations of fungicides were used to some extent in an effort to improve the fungicidal efficiency of the respective chemicals. In this respect Crag apple fungicide 341C was mixed with Fermate, Puratized Agricultural Spray with Fermate, Fermate with Flotation sulfur and wettable sulfurs, Phygon with Fermate, Arathane W with Bioquin 1 and also with Puratized Agricultural Spray. The season was such that little was learned as to the efficacy of the above split schedules or combinations.

Phygon, Cr. 305, Tag HL 331, Puratized Agricultural Spray, and liquid lime-sulfur appeared to serve best in controlling the disease. Phygon dust appeared to be very effective in this respect. Since the mercury materials

were used in split schedules, their efficiency was confined to the bloom and first cover applications. Fermate, Crag Apple Fungicide 341C, Puratized Apple Spray, and the wettable sulfurs (Flotation included in this group) appeared next in importance, while the remainder of the compounds varied considerably in their performance from test to test. Fermate, for some reason, was not particularly effective in the South Atlantic States where heavy infection took place early. Cr. 305, a relatively new addition to the list of fungicides, was used in a number of the tests and appeared to possess some promise as a fungicide. Actidione was used in several tests but gave poor scab control.

In one test in Maryland where the control of scab was difficult, considerable success was obtained by applying Elgetol to the floor of the orchard just as the buds were breaking, and following this up with Tag HL 331 at the late calyx period.

Considering the merits of the various materials on the basis of their effects upon the plants, Phygon, Cr. 305, Tag HL 331, Crag 341C, and liquid lime-sulfur were found to possess objectionable characteristics. Phygon XL was found to russet Delicious fruit in Massachusetts, and this was thought to be caused by the added magnesium sulfate. In Massachusetts chlorosis of leaves also developed but the size of the fruit was normal. In Virginia Phygon + DN-111 caused severe fruit injury and in Pennsylvania the typical leaf chlorosis was observed. In Kansas severe fruit russeting developed on the fruits of the Winesap but not on the Jonathan varieties. In North Carolina the material produced delayed maturity. The addition of magnesium sulfate to Phygon at the Ontario station appeared to reduce chlorosis but it was observed that the trees sprayed with Phygon in 1948 produced a short crop in 1949. This was also observed in New York and New Hampshire. At the Nova Scotia station Phygon dust caused headaches with the personnel, and a paling of the treated leaves.

Cr. 305, used for the first time at many of the stations, produced russeting of the fruit at the New York, Vermont, Virginia, West Virginia, and Maine stations. At the New York station Cr. 305 treated fruits remained small, while at the Maine station the leaves were russeted and the fruit was spotted. Cr. 2228, 2256, 2320 caused russet of fruit at the Virginia station.

Actidione was found to cause severe leaf injuries and generally had to be dropped from the schedules after a few applications. Crag 341C, as nearly as we could tell, was used generally with lime. There were a few stations reporting its use without lime but probably the lime used was not set up in the tables presented to the committee. Foliage yellowing was observed very early in the season at the Vermont station, and fruit russeting was noticed at the New York station as well as leaf spotting and marginal burn which apparently was enhanced by dry, hot weather. At the Virginia station it was noted that the material irritated the personnel and caused serious petal injury at pre-pink. Foliage was also injured at an early stage and the injury was characterized as a contraction of the under surface of the leaves. Where DN-111 was mixed with 341C injury was much less pronounced. Russeting of fruit and leaf injury by 341C was reported from West Virginia on certain varieties. At the Ontario station this material did <u>not</u> cause any russeting such as was experienced in 1948.

Liquid lime-sulfur and the wettable sulfurs all were observed as causing their typical reactions on both leaves and fruits. In British Columbia where lime-sulfur was applied in concentrate machines, a considerable reduction in injury was observed with this practice. Tag HL 331 was observed as causing fruit russet and leaf injury in Vermont, while in British Columbia an application made closely on top of a residue of Fermate-Mulsoid sulfur was followed by a severe chlorosis and defoliation of Delicious apple trees. In Virginia it was also observed commonly that considerable leaf yellowing, necrosis, and defoliation was caused by the application of the mercury compounds on top of residues of Fermate. A severe leaf injury developed following the use of Merthon 642 in Virginia, when combined with DN-111 and Rhothane. In New York the mercury compounds apparently delayed the maturity of the fruit.

Fermate was usually recorded as being the safest material used. At one of the New York stations some stippling of the fruit of Rhode Island Greening was observed with the advent of high temperatures and in Virginia an enlargement of lenticels was noted where the material was used.

Some of the lesser used materials were also observed as causing some injury. H 258 A caused severe injury to fruit in Virginia and Maine, and leaf-shot-hole in Maine. Goodrite Z.I.P. caused typical zinc russeting of fruit in Virginia. Stanofide caused a chlorosis of foliage at one station. Hecla copper oxide caused a severe leaf fall and some fruit injury in Virginia and West Virginia, while Arathane emulsion caused a severe fruit russet in Oregon. The powdered Arathane W did not possess these characteristics to the same degree as the emulsion form.

RUST

Two rust experiments were reported. In the Virginia test various Cr. compounds, Goodrite Z.I.P. and Z.A.C., Magnetic 70, Puratized apple spray, Puratized Agricultural spray, Puratized 806 sprays, and Fermate were compared. The dithiocarbamate salt proved to be the best, while the mercury and Cr. compounds proved to be inferior. At the Poughkeepsie, New York, station Fermate, Cr. 305, Crag apple fungicide 341C, Crag apple fungicide 341C + Fermate, Phygon, Micronized sulfur, Puratized Agricultural Spray, Puratized Agricultural Spray + Fermate, and Tag HL 331 were compared. All of the sprays containing Fermate ranked first in control. Crag apple fungicide 341C was next, while all the others were unsatisfactory. Cr. 305 proved to be the poorest.

FRUIT SPOT (BROOKS)

Spot control experiments were conducted in New Jersey and in West Virginia. Ordinarily this disease is held under control in our properly sprayed orchards but for some reason or other many complaints concerning this trouble have come to our attention during the past two years. In the New Jersey test the applications started at prepink and continued until the 3rd cover. This was a normal spray schedule for apples. Lime-sulfur, wettable sulfur, Fermate, Crag apple fungicide 341C, Esso SR-406, Apple and Agricultural Puratized, and Tag HL 331 were compared. Of these materials Fermate and Esso SR-406 were the most satisfactory, while sulfur, lime

sulfur, and the mercury compounds proved to be the poorest. The mercury compounds, wettable sulfur, and Fermate were the safest, while lime-sulfur and Crag apple fungicide 341C caused some injury. Fermate and Esso SR-406 were considered as best, considering both control and safety, to use against this disease.

In West Virginia, Bordeaux mixture and Fermate were compared in a spray timing experiment on the Rome Beauty variety, while Fermate only was used on the Golden Delicious variety. The orchard had already received several previous sprays of other materials to control scab. The best control on the Rome variety was achieved by applying five cover sprays of Bordeaux mixture, starting May 27. The critical period for control on Rome appeared to come, in 1949, between the middle of June and the middle of July at which time both Bordeaux mixture and Fermate performed quite well in holding down the disease. On the Rome variety the best single spray was that one applied in the first week in July. On Golden Delicious no single application of Fermate was very effective and it was necessary to use at least three applications (beginning in the middle of June) of this material to get effective control.

FLY SPECK

One experiment was conducted in West Virginia against this disease on Rome Beauty and Golden Delicious. On Rome, Bordeaux mixture and Fermate were compared in a timing tests; and Fermate was used alone on the Golden Delicious variety. Apparently no single application of either material was very effective in controlling the disease. The best control, however, on both varieties with a single application, occurred when the materials were used about the middle of July, at which time both Bordeaux mixture and Fermate were about equal in performance. The best results followed the use of all five cover applications but the most economical series of sprays were those starting in early July and ending in early August. In general, it appeared that Fermate was more effective against this disease than Bordeaux mixture.

SOOTY BLOTCH

West Virginia reported one test against this disease. Like the Fly Speck experiment, the materials were applied in a timed series to discover the most effective period for control. Bordeaux mixture and Fermate were used on the Rome Beauty variety, while Fermate was used on the Golden Delicious variety. For Bordeaux mixture the best single application occurred in the middle of July, while with Fermate the best single application occurred in late May. Generally speaking, Bordeaux mixture was more effective than Fermate in the control of this disease on the Rome variety. The most effective series of applications of Bordeaux mixture and Fermate were those applied to the Rome variety between the last of May and the first week in July. On Golden Delicious the most effective series was that applied between the middle of June and the middle of July. These tests indicate that more attention to timing is necessary for the exact control of both Fly Speck and Sooty Blotch.

BITTER and BLACK ROT

One bitter rot and black rot control test was reported on from North Carolina. Nine applications were made on these plots: bloom, calyx, and seven covers. Forty-three percent of the fruit of the unsprayed trees suffered from bitter rot and 70 percent of the fruit was affected by black rot. Lime-sulfur, flotation sulfur, Phygon, Fermate, Cr. 305, Crag apple fungicide 341C, Puratized Agricultural Spray, and Tag HL 331 were used for comparison. Bordeaux mixture was applied to six covers of the lime-sulfur and Tag HL 331 plots, while Phygon was applied to the six covers of the Puratized plot. The best bitter rot control was experienced in the plots where Bordeaux mixture was used in the six cover plots and in the plot sprayed with Fermate. For the control of black rot of fruit none of the materials proved to be very effective. The best results appeared to follow the application of Tag HL 331 followed by Bordeaux mixture and Puratized Agricultural Spray followed by Phygon. Apparently the critical control was tied up with the early applications.

POWDERY MILDEW

Apple powdery mildew drew some attention in British Columbia, California, and Washington. At the British Columbia station at Summerland, Actidione, the antibiotic recovered from the staling liquor of growing Streptomyces griseus cultures, was used on Jonathan apple trees at the delayed dormant, prepink, pink, and calyx periods of growth. No report was made as to its effect upon the fungus but it was found that the material injured the foliage, caused a poor set, and a raised russetting of the fruit. At the California station Arathane W 25 and liquid lime-sulfur were compared. Arathane was found to be superior to lime-sulfur in the control of leaf infection. The lime sulfur caused leaf injury.

The two Washington stations were located at Yakima and at Wenatchee. At the Yakima station on the Jonathan variety Actidione, lime-sulfur, Arathan W and E Sulforon, tank-mixed Parzate, Esso SR-406, and $KMNO_4$ + wettable sulfur were compared. The materials were applied at early pink, early calyx, and first cover. The best control followed the use of lime-sulfur followed by the wettable sulfur (Sulforon), Arathane, $KMNO_4$ + sulfur, tank-mixed Parzate, Esso SR-406, and Actidione in that order. The lime-sulfur solution caused some marginal injury to leaves, while the Actidione antibiotic caused a severe spotting of the leaves.

At the Wenatchee station quite an extensive experiment was conducted. Here lime-sulfur solution was compared with Kolodust, Arathane W, Cr. 305, Fermate, Karbam Black, Zerlate, Zerlate + sulfur, Phygon XL, Parzate, Tag HL 331, Crag apple fungicide 341C + lime, Isothan 215, Vancide 30-W and 38-W, Preventol GD (G4) XP-41A and Actidione. The lime-sulfur was used at two concentrations at pink and calyx and also at one concentration at pink and calyx that was followed by Kolofog at first cover in one case and with Arathane W and Mike sulfur at four covers in two other cases. Zerlate + sulfur in all six applications gave the best control. Cr. 305 was next and Kolodust third. Arathane W following lime-sulfur and Kolofog following lime-sulfur came next and these were followed by lime-sulfur solution and lime-sulfur solution followed by Mike sulfur. Zerlate alone, Fermate, Phygon

XL, Karbam Black, Parzate, Tag HL 331, Crag 341C + lime, Isothan Q15, Vancides 30W and 38W, Preventol GD (G4), and Actidione failed to show promise. XP-41A was used only on several trees but showed some promise.

Actidione at 9 p.p.m. caused severe leaf burning and some injury at 3-5 p.p.m. Phygon XL caused leaf speckling and fruit blotch by late August, and Zerlate + sulfur, which gave the best degree of control, caused a slight scalding of the fruit in August.

FIRE BLIGHT

Colorado reported the use of Dithane Z78 + Triton B 1956 at 10 percent bloom and full bloom as being of some benefit in the control of fire blight.

CHERRIES

LEAF SPOT

Reports of leaf spot control experiments were sent in from Indiana, Pennsylvania, Wisconsin, and Ontario, Canada.

In Indiana early infection was light and a buildup did not occur until rainfall became more plentiful in late summer. Crag fungicide 341C + lime was compared with Bordeaux mixture and with Crag 341 - Bordeaux mixture in alternate sprays. These treatments were given to young nursery trees and 13 applications were made beginning in late April and extending through most of August. None of the materials used caused injury to the foliage. The best control occurred with the trees sprayed with Bordeaux mixture. The alternate schedule was next and Crag 341C was last.

At the Wisconsin station also the season was dry early and infection did not show up until after bloom on unsprayed trees. No leaf spot developed on any of the plots, so no information was developed as to the fungicidal properties of the various materials used. The materials used in four applications in these plots included Bordeaux mixture, Dithane D 14 + zinc sulfate, Cop-O-Zink, Tennessee Copper 34, Fermate, Crag 341B, C.O.C.S., and Crag 341C + lime. Split schedules were used in most of the plots with many of the above materials. When the fruit was sprayed with Fermate they turned dark and had a uniform color, while those sprayed with Crag 341 usually never turned dark in color.

From Pennsylvania two reports were submitted. In the first report five applications were made, at petal fall, shuck, and three covers. All plots were sprayed with lime sulfur in pink and Bordeaux mixture at post-harvest. Fermate, Crag 341B, Tennessee copper 26, and lime-sulfur-bordeaux mixture were compared. The best control resulted from the use of Fermate and Crag 341B. Next best was Tennessee copper 26 and the poorest control followed the use of the lime-sulfur-bordeaux mixture. Fermate proved to be the safest, while the lime-sulfur-bordeaux mixture combination caused the greatest injury. This injury was characterized by leaf scorching and fruit dwarfing. Crag 341B caused some marginal and spot necrosis and a bronzing of the leaf surfaces. The copper material caused leaf spotting, yellowing and leaf drop and fruit dwarfing.

In the second experiment the entire orchard was sprayed with lime-sulfur in pink. The treatments with the following materials took place at

petal fall, shuck and three covers. Tennessee Copper 26, Cop-O-Zink, Hecla cuprous oxide, Crag 341C, Crag 341SC, Crag 341B followed by sulfur + Zerlate, Crag 341B followed by sulfur + Fermate Cr. 305 and Phygon XL were used in the separate plots. The best control was exhibited by the Crag fungicides 341C and B. When followed by sulfur + Zerlate, however, 341B was inferior to 341B when used alone or when followed by sulfur + Fermate. Crag 341SC, made with the pure stearic acid, was considerably inferior to Crag 341C made with a mixture of high molecular fatty acids. The copper materials were next in order of efficiency, while Phygon XL and Cr. 305 were the poorest. Crag 341B followed by sulfur + Fermate proved to be the safest combination used, while Cr. 305 and Phygon XL proved to be unsafe. Cr. 305 caused small dead spots around the apical end of the fruits.

In Canada, at St. Catherines, leaf spot was not much of a factor in cherry growing this season and was easy to control. C.O.C.S. + lime, Cr. 305, Phygon + $MgSO_4$, Crag 341B, and Esso SR 406 were compared. Since no disease showed up nothing was learned of the fungicidal properties of these materials. The copper material proved to be safest under the circumstances of this list, while Phygon + $MgSO_4$ caused the greatest injury.

BROWN ROT

One report was submitted from Oregon and one from Washington. In the test against blossom blight of sweet cherries, Puratized Agricultural Spray, Phygon XL, Fermate, Tag HL 331, Arathane W and Esso SR-406 were compared. Very little blossom blight developed during the early season and no comparison could be obtained as to the merits of the materials used. In the Washington State report Arathane, Fermate Phygon XL, Roccal, Puratized Agricultural Spray, Crag 341C and lime-sulfur solution were compared as to their value in controlling brown rot spur blight. The applications were made at the pop-corn stage of bloom and 30 days later. The best control developed where the mercury compound was used followed closely by the Crag fungicide 341C + lime, Roccal, Phygon, and Fermate. The control with Arathane proved to be the poorest. Lime-sulfur and Arathane caused injury to the flower petals.

PEACHES

BROWN ROT

The disease during the 1949 season was not so important to peach growers as it was during the 1948 season. Even in the South losses were not so heavy as in former seasons. Probably the greatest damage occurred in the South Atlantic States. In the deep South and in the northern States the weather was generally dry at picking time and although a considerable potential of brown rot was present in many of the orchards, the fruit moved to market in fairly good shape. South Carolina, Virginia, and some Delaware and Maryland orchards reported considerable rot and this was due, no doubt, to heavy rains that developed at picking time in these areas.

The early spring all along the Atlantic Seaboard and into the South was marked by a long blooming season. Coupled with this was the delaying effect on the blooming habits of a number of varieties brought about by the

lack of enough cold treatment owing to the relatively warm winter. It was almost impossible in most of these areas to work out a satisfactory schedule of spray applications to protect any great portion of the developing bloom. As a result in many places considerable blossom blight developed despite the effort to control it.

North Carolina, in cooperation with the U. S. Department of Agriculture, reported one blossom blight control experiment. In this test three applications of liquid lime-sulfur were made during the early part of the bloom period up to the time when about 50 percent of the bloom were open. Counts at harvest time showed extensive brown rot losses on all plots, indicating that not enough of the blooms were protected.

In Delaware a report was submitted which shows the relation of the protection of bloom to the amount of potential inoculum that can be built up in the orchard at harvest time. Here it was shown that the number of bloom applications bears a direct correlation with the number of spore producing surface (blighted bloom, current season cankers, rotted fruit, etc.) found in the orchards.

In South Carolina two tests were reported where some effort was made to control brown rot at the blossom stage. In the first test liquid lime-sulfur, Phygon, wettable sulfur, Puratized Agricultural spray, and manganese ethylene bis dithiocarbamate were used at blossom time. In some cases two applications were made and in others only one bloom spray was applied. The cover sprays (post bloom) varied somewhat among the plots but all received at least one sulfur application, while others received a full complement of seven applications of sulfur. Phygon, Cr. 305, liquid lime-sulfur, or manganese ethylene bis dithiocarbamate were also used in some of the cover sprays. In the first test some of the fruit was held in cold storage for four days and then at room temperature for three days, while some was held at room temperature for five days before the counts on brown rot control were made. When the fruit was held in cold storage for four days and then brought out into the packing shed for three days, no rot developed on fruit receiving one application of either Phygon or lime sulfur in bloom and either seven or six applications of wettable sulfur following bloom. The poorest control developed where Puratized was used once in bloom and wettable sulfur was used in the first cover and Cr. 305 was used in the next six applications. When the fruit was held for five days at room temperature, the same general differences were noted but, of course, relatively more rot developed because of the differences in temperature.

The second test, conducted in another block of trees, was quite similar to the first. In this test Zerlate, Parzate, Dithane Z78, wettable sulfur, and liquid lime-sulfur were used in the cover applications in various sequences. Liquid lime-sulfur, Phygon, and Puratized Agricultural Spray were used on the bloom sprays either at pink or at full bloom. One lot of the harvested fruit was held at room temperature for six days and one lot was held at cold storage for five days followed by room temperature for four days. With the lot of fruit held at room temperature for six days the best control of brown rot developed on those fruits harvested from the trees that received no bloom sprays but were sprayed with wettable sulfur in the seven cover applications. The poorest control among the sprayed plots developed where lime-sulfur was applied at the pink stage and this was followed by seven applications of wettable sulfur. With the fruit held at cold storage

followed by room temperatures, the best control was found where lime-sulfur was applied at full bloom and seven cover applications were made, while the poorest control followed the use of Phygon XL at full bloom and one application of wettable sulfur at shuck-off and six applications of Parzate. There is a great deal of conflicting data in these experiments but generally speaking the use of liquid lime-sulfur at bloom and wettable sulfurs at shuck-off and covers is indicated as a good program for brown rot control during the growing season.

In Delaware one pre-harvest test was developed for the control of brown rot. The trees received from two to five applications, according to variety, prior to picking. Liquid lime-sulfur, wettable sulfur, Clorox, Isothan Q15, Parzate, Z78, Phygon XL, Cr. 305, H 258 M, manganese ethylene bis dithiocarbamate, Bioquin + Sulforon x, and Bordeaux-Sulforon x were used. None of these materials had any influence on cutting down the rot at the packing shed. Isothan Q15 and H 258-M defoliated the trees following one application. None of the others appeared to cause any injury.

In a test designed to find out whether brown rot control could be obtained after harvest, packaged peaches were dipped in various suspensions and solutions of fungicides in one Delaware test. Liquid Chlorax, powdered Chlorax, Clorox, calcium chloride, copper sulfate, nitrogen trichloride, Actidione, manganese ethylene bis dithiocarbamate, liquid lime-sulfur, liquid lime-sulfur + Sulforon x, liquid lime-sulfur + Clorox, liquid lime-sulfur + calcium chloride, and liquid lime-sulfur + copper sulfate were used. The best control developed in the tests with liquid lime-sulfur. All of the other materials were inferior to lime-sulfur as far as control was concerned. In addition, Actidione, nitrogen trichloride, powdered Chlorax, and lime-sulfur + Chlorax were found to be less safe than lime-sulfur to the treated fruits. Actidione (5-20 p.p.m.) was very injurious to the treated fruit.

An experiment on brown rot described from the Ontario station, near St. Catherines, in which Micro-sulfur, Magnetic sulfur paste, Cr. 305, Phygon XL + $MgSO_4$ and Esso SR-406 were compared at pink, shuck, and two covers, produced no data relative to control since rot was not a factor. The cooperator reported that there was a possibility that the fruit sprayed with the organics may have been reduced in size.

POWDERY MILDEW

One report from California described the use of Arathane W and lime-sulfur for the control of this disease. Lime-sulfur solution at 1.5% was very effective in reducing the number of shoots showing the systemic infection but too much injury followed its use. Arathane, on the other hand, although not quite as effective as lime sulfur, caused no injury. This is another indication that Arathane may be quite useful in controlling this type of disease. In another test conducted at the Puyallup, Washington station a polysulfide compound, Roccal, Fermate, Puratized Agricultural Spray, Phygon, Bordeaux mixture, and 341C were compared. The polysulfide compound caused a serious twig injury. The best control followed the use of Roccal 10%, 8 quarts to 100 gallons, and Puratized Agricultural Spray at 2 quarts to 100 gallons. Fermate and Bordeaux were next best, while Phygon and the lower concentrations of Roccal and Puratized Agricultural

Spray were inferior. The polysulfide, a mixture of sodium polysulfide and thiosulfate failed to have any influence on the disease. All of the materials, applied at dormant in two applications, with the exception of the sulfide, were found to be safe.

BLIGHT

One report was received from British Columbia concerning this disease. Applications of Fermate were made in September and again at the pink stage of bloom. In the dormant stage two applications of lime-sulfur were made in March and April. No figures were given on disease control but the cooperator reported that considerable dieback developed among the shoots of the above treated trees, while none was observed in adjacent trees receiving only the dormant sprays. Commercial growers who used Fermate in the September sprays but no dormant lime-sulfur reported that their peach trees also developed dieback. The winter was extremely cold in this area last year and possibly the Fermate had prevented the wood from becoming hardy before the cold weather arrived.

BACTERIAL LEAF SPOT

Bacterial leaf spot tests reports were received from Georgia, New Jersey, and South Carolina. One report from New Jersey described the use of zinc-lime, zinc oxide, zinc sulfide, neutral zinc sulfate, basic zinc sulfate, and Esso SR-406 in a day and a night test to control this disease. Considerable spot developed in all the trees. None of the materials proved to be effective in the night applications. In the day applications zinc-lime (tank mixed) again proved to be the best material to use for a partial control of this disease. No injury developed this season from any of the materials used.

In South Carolina reports were received from the Gilbert and Johnston areas. At the Gilbert station zinc-lime and Esso SR-406 were applied in a series of three rapid applications in a ten-day period, just as the leaves were breaking out. A mist blower employing 4x concentrates was used to apply the materials in a day versus night operation. Very little bacterial leaf spot developed in the region due to the dry, cold conditions that prevailed in the early season and no valid comparison of the treatments could be made. It was found that a very good coverage resulted when such an apparatus was used and that the amount of spray material generally used could be cut in half to maintain a very good residue. No injury resulted from any of the materials used.

In the experiment reported on from the Johnston, South Carolina area the test was set up so that spring and summer treatments were superimposed on fall treatments and these were compared with plots treated in the spring and summer. As at Gilbert, very little leaf spot developed due to the dry, cold weather in the early spring. Bordeaux mixture, zinc-lime, Tennessee Copper 26, and lime were used in the fall dormant applications to see if any suppression of bacterial infection was possible at that time. Zinc-lime, Woolfolk Peach Pan, Niagara Peach Spray, Nu-Z, and Delmo-Z were compared in the spring and summer treatments. One application was made in the dormant series and generally six applications were made in the spring-early summer series. The differences in control, or lack of control,

between the various plots were not significant and nothing was gained from the tests.

In the Georgia tests Z.A.C., Bordeaux mixture, lime-sulfur, wettable sulfur, basic zinc sulfate, acid zinc sulfate, and Phygon were compared. Four weekly applications were made during a long blooming period. Some control was evident in the plots sprayed with the basic zinc sulfate. This was thought to be correlated with the better vigor produced in the trees sprayed with this material.

APRICOTS

BROWN ROT

In this test in California, Fermate and Phygon were applied as sprays at full bloom and at petal fall stages of blossom growth to control blossom and twig blight. Phygon gave the best control but Fermate was the safest.

RASPBERRY

YELLOW RUST

Oregon reports that lime-sulfur, Cop-O-Zink, Phygon, Zerlate, and Fermate were applied in a single application at delayed dormant in one test near Corvallis. All of the materials appeared, under the conditions of the test, to be equally efficient and equally safe. Preference was made for lime-sulfur because of its low cost and availability.

ANTHRACNOSE

In a New York test Zerlate, Fermate, Bordeaux mixture, Tennessee Copper-26, C.O.C.S., Puratized Agricultural Spray, and Puraturf 177 were compared. These materials were applied when the new canes were 10-15 inches high and also at prebloom. The mercury compounds were only applied when the canes were 10-15 inches high. The best control was obtained from the use of Zerlate and Fermate. They were also found to be the safest.

STRAWBERRY

RED STELE

In Colorado, soil drenching with suspensions of Dithane Z-78, Parzate, and copper sulfate were compared as to control of the *Phytopthora* organism in the soil. Apparently all of the materials proved to be of some value since all the treated plots show a degree of control. The plots treated with Dithane Z-78 showed the least injury to plants and also the best yield.

AVOCADO

DOTHIORELLA ROT

In California experiments were conducted to control Dothiorella rot. Bioquin 1, Dithane D 14, and Phygon XL + magnesium sulfate were compared. Bioquin was used in two plots; using one application in late September in one, and two applications in the other on September 20 and November 5. Dithane D 14 was applied in two similar applications but instead of using a conventional hydraulic rig, the material was fogged on with a special machine. The application of Phygon XL-$MgSO_4$ was made with the conventional rig on September 20 and November 5. Bioquin 1 was the only one which gave control and also proved to be the safest of the three. The two applications of Bioquin 1 proved superior in control to that of the one application.

CITRUS

LEMON BROWN ROT

Experiments reported on in 1948 were again repeated in 1949 at the Riverside Experiment station. A number of chemicals were used and the best control of this disease resulted from the use of Ferric Dithane, followed closely by the chromates (Crag) 169, 531, 640, and 658. Arathane, Phygon, and Bordeaux mixture were also very effective. The poorest control developed where Rosinamine D silver nitrate was used.

ALMOND

BROWN ROT

California reported one test on this disease. Bordeaux mixture, Fermate, Zerlate, Phygon XL paste, Puratized Agricultural Spray, Arathane, General Chemical 692 + General Chemical 308, Crag 341C, Crag 531, and Crag 640 were used to control the disease. One application was made at the pop-corn stage of bloom. None of the materials caused any injury. The best control developed in the plots sprayed with Bordeaux mixture and Crag 640. Phygon XL paste and Puratized Agricultural Spray came next, Arathane was next, followed by the dithiocarbamates. The dithioacetates and Crag 341C were the poorest.

GRAPE

BLACK ROT

One test was reported on from Missouri. The early season was dry but rains were frequent and the humidity was high during the summer. Primary infection was light but secondary fruit rot was serious. Fermate, Dithane D 14 + zinc-sulfate, Arathane W, Cr. 305, Esso SR-406, and Bordeaux mixture were used for comparison. The best control followed the use of the dithiocarbamates and Esso SR-406 at 4 pounds to 100 gallons. The poorest control

followed the use of Esso SR-406 at 2 pounds per 100 gallons, Cr. 305, and Arathane W in that order. The safest was Fermate while the most injurious was found to be Bordeaux mixture.

PECAN

SCAB

In Georgia, Bordeaux mixture, Zerlate, Bordeaux mixture first two applications followed by Zerlate in three applications, and Phygon were compared as to control of pecan scab. The best treatment appears to be the split applications of Bordeaux mixture followed by Zerlate. This gives good control, fewer black aphids, and cuts down the amount of injury usually associated with applications of late Bordeaux mixture. Zerlate has been found to cause irritation to the skin of some of the spray operators.

WALNUTS

BACTERIOSIS

In Oregon Bordeaux mixture, yellow Cuprocide, Compound A, Crag Potato fungicide 658, and Tag HL331 were compared as to their control of walnut blight or bacteriosis. Bordeaux mixture proved to be the best bactericide but caused the greatest injury. Compound A, although not so effective as Bordeaux or Yellow Cuprocide, proved to be the safest under the conditions existing this year. The Crag fungicides proved to be inferior to the others in control. Three applications were made: early prebloom, late prebloom, and early postbloom.

DATES

FRUIT SPOILAGE

One report from California states that Thiomate "19", a mixture of Fermate 3.41%, sulfur 92%, and inactive ingredients 4.59%, applied as a dust has proved the most effective, least expensive, and most easily applied fungicide so far found for controlling fruit spoilage.

CRANBERRY

FRUIT ROT

Cranberry rot tests were conducted at the East Wareham, Massachusetts experiment station. Fermate dust, 50-50 with talc, at the rate of 50 pounds per acre, Fermate spray 2-100, 10-4-100 Bordeaux mixture, and copper-zinc-chromate 2-100 at the rate of 250-300 gallons per acre were used to control rots at early bloom and at the end of bloom. The dust was used on wet vines and gave the best control followed by Fermate spray and Bordeaux mixture. The Chromate compound was found to be ineffective in rot control.

EFFECTIVENESS OF MATERIALS ON FRUITS

ARATHANE (dinitrocapryl crotonate). This was good in Washington and British Columbia for controlling powdery mildew of apples. Also good for powdery mildew of peaches. It was very poor and caused some injury when used to control brown rot spur blight of cherries. Also poor for black rot of grapes. It was fair for brown rot of lemons and brown rot of almonds.

ACTIDIONE. No good for controlling apple scab or powdery mildew and also caused injury. Very injurious to peaches and gave inferior brown rot control.

BIOQUIN 1. Little interest and not tested.

CR 305. Looks promising for control of apple scab and possibly apple mildew but only fair for grape black rot. It was unsafe on cherries.

CRAG 341C. Very good control of brown rot spur blight of cherries but seemed to prevent fruit from coloring up properly when used for leaf-spot control. Fair for lemon brown rot and apple scab, and inferior for apple mildew and walnut bacteriosis.

CRAG 658. Promising for lemon brown rot but not so good as Dithane. Also good for almond brown rot.

DITHIOCARBAMATES. Ferbam fair for apple scab but not effective in South Atlantic States. Very safe on apples. Very good for fruit spot, fly speck, bitter rot, rust, and apple black rot (not of fruit, however), but no good for mildew. Good for cherry leaf spot but not brown rot spur blight. Not so good as Phygon for apricot brown rot but safer. Zerlate and Fermate both very good for rust and anthracnose of raspberry. DITHIOCARBAMATES best for grape black rot and fair for almond brown rot. For some reason the Dithanes were not tested extensively the past season on fruits.

ELGETOL. One of the newest developments in apple scab control was the report of Goldsworthy and Dunegan on use of Elgetol as a ground spray followed by use of TAG 331 at late calyx period.

G.C. 308 and 629. Were reported only in a test for almond brown rot control and gave poor results.

PHYGON. Still a good fungicide but causes too much injury. Phygon dust looks very good for apple scab control but no good for apple mildew. Phygon XL unsafe on cherries. Good control of apricot brown rot but too much injury. Good control of raspberry rust and non-injurious. Also effective for lemon brown rot.

PURATIZED APPLE SPRAY)
PURATIZED AGRICULTURAL SPRAY). Very good control of cherry brown rot spur blight with Agricultural Spray. Good control of apple scab with this

and fair with the Apple Spray. Ineffective for raspberry anthracnose.

<u>SR 406</u>. Good for apple fruit spot but not too good for apple mildew or bacterial leaf spot of peaches.

<u>TAG HL 331</u>. Good with apple scab but no good for apple mildew.

RESULTS WITH VEGETABLE DISEASES

POTATOES

NO DISEASE PRESENT

NEW JERSEY (Cranbury). Descending order of yield for sprays was: Dithane D-14, Parzate Liquid, Tribasic, Cop-O-Zink, Dithane Z-78, SR406, Crag 658, and Bordeaux. For dusts it was: Cop-O-Zink, Tribasic, Crag 658, and Dithane Z-78.

WASHINGTON (Mt. Vernon). No yield differences given -- disease absent.

PENNSYLVANIA (State College). In descending order of yield: Crag 658, Bordeaux, Dithane D-14, Cop-O-Zink, Phelps Dodge Cu, and Tribasic.

SOUTH CAROLINA (Charleston). No disease and no differences in yield or control.

LATE BLIGHT

ALABAMA (Gulf Coast Substation). Descending order of control was: COC-S, Crag 658, Dithane D-14, Dithane Z-78, Tribasic, and Phygon XL all alike, a weaker Dithane Z-78 defintely poorer, and the untreated check. In descending order of yield: Phygon XL, Dithane Z-78 (6%), Tribasic, Dithane D-14, Crag 658, COC-S, Dithane Z-78 (3.9%), check.

NOVA SCOTIA (Kentville). In descending order of disease control: Bordeaux, COC-S, Basicop, Perenox, and Dithane all ranked alike, DDT check poorest. In descending order of yield: COC-S best, followed by Bordeaux, Basicop, Perenox, and Dithane all ranked alike, and DDT check lowest.

FLORIDA (Homestead). In descending order of disease control Dithane D-14, Crag 658, SR406, Tribasic, and Cop-O-Zink all ranked alike, manganese ethylene bis dithiocarbamate and Dithane Z-78 alike, Parzate, and Cr305. In descending order of yield: Dithane Z-78 highest, all others alike except Tribasic which ranked lowest.

P.E.I. (Charlottetown). Standard materials in descending order of disease control: Bordeaux, Basicop, COC-S, Perenox, Dithane D-14, and Parzate. In descending order of yield: Bordeaux, Parzate, COC-S, Basciop, Perenox, and Dithane D-14. New materials, in descending order of disease control: Bordeaux, Cop-O-Zink, and Crag 658 alike, SR-406 and Phygon XL alike, and Zac poorest. In descending order of yield, Cop-O-Zink and Crag 658 alike, SR-406, Zac, Bordeaux, and Phygon XL.

EARLY BLIGHT

DELAWARE (Selbyville). In descending order of disease control: Manganese ethylene bis dithiocarbamate, Parzate fungicide, Dithane Z-78, and Dithane D-14 all ranked alike; Crag 658; Tribasic, Robertson Copper, and Parzate-Bordeaux schedule alike; Bordeaux, Copper A, Cop-O-Zink, Cuprocide Y, and Zac alike; Phelps Dodge Copper and Zerlate alike; and untreated check poorest. In descending order of yield: Dithane Z-78,

Zac, manganese ethylene bis dithiocarbamate, Dithane D-14, and Parzate Liquid all alike; Cop-O-Zink; Cuprocide Y and split schedule of Parzate-Bordeaux; Tribasic, Robertson Copper, Crag 658, Zerlate, and Parzate fungicide alike; Bordeaux, Copper A, and check alike; and Phelps Dodge Copper lowest.

MICHIGAN (Lake City). In descending order of disease control: Dithane D-14, 308, Bordeaux, Crag 658, Cop-O-Zink, Dow 926, Parzate, 1124, 1189, Tribasic and EM25-3. In descending order of yield: Dithane D-14, 308, Dow 926, Crag 658, Bordeaux, Cop-O-Zink, 1189, 1124, Parzate, Tribasic, and EM25-3.

NORTH DAKOTA (Northwood). In descending order of disease control: Parzate dust, Parzate spray, Cop-O-Zink spray, 1189 spray, Zinc nitro-dithioacetate spray, Cop-O-Zink dust, Dithane Z-78 dust, Tribasic spray, Robertson Copper dust, Tribasic dust, and untreated check. In descending order of yield: Parzate dust, 1189 spray, Cop-O-Zink spray, Parzate spray, Dithane dust, Cop-O-Zink dust, Tribasic spray, Tribasic dust, Robertson Copper dust, zinc nitro-dithioacetate spray, and the untreated check.

MINNESOTA (Crookston). In descending order of yield (differences not significant): Untreated check, Crag 658 dust, Parzate fungicide dust, Bordeaux spray, Parzate liquid spray, Tribasic dust, Tribasic spray, Cop-O-Zink dust, untreated check, Dithane Z-78 spray, Copper-Lime dust, Dithane Z-78 dust, Crag 658 spray, and Cop-O-Zink spray.

OHIO (Apple Creek). In descending order of disease control: Dithane Z-78, Parzate fungicide, Cop-O-Zink, Zac and Parzate liquid, COC-S, Dithane D-14, Crag 658 and Robertson Copper, Zerlate, Tribasic, Methasan, check. In descending order of yield: Parzate fungicide, Zac, Dithane Z-78, Cop-O-Zink and Parzate Liquid, Dithane D-14 and Tribasic, Zerlate, COC-S, Methasan and Robertson Copper, Crag 658, and check.

OHIO (Marietta). In descending order of disease control: Dithane D-14, Parzate liquid, Parzate fungicide, Dithane Z-78, Cop-O-Zink, Methasan, COC-S, Robertson Copper, Zerlate, Crag 658, Zac, Tribasic, and check. In order of descending yield: Methasan, Robertson Copper, Dithane D-14, Parzate fungicide, Zac, Parzate liquid, Zerlate, Crag 658, Cop-O-Zink, Dithane Z-78, COC-S, Tribasic, and check.

OHIO (Willard). In descending order of disease control: Dithane D-14, Dithane Z-78, Crag 658, and Parzate liquid all alike; Parzate fungicide; Methasan; Tribasic; COC-S; Zac, Zerlate, and Robertson Copper alike; untreated check. In descending order of yield: Parzate fungicide, Dithane D-14, Dithane Z-78 and Parzate liquid alike, Zerlate, Zac, Methasan, COC-S, Tribasic, Robertson Copper, Cop-O-Zink, Crag 658, and check.

OHIO (Wooster). In descending order of disease control: Dithane Z-78; Dithane D-14, Parzate, and Parzate liquid all alike; Crag 658; Zac; Cop-O-Zink; Tribasic, and Methasan alike; Robertson Copper and COC-S alike; Zerlate, and check. In descending order of yield: Dithane Z-78, Parzate liquid, Parzate fungicide, Dithane D-14, Methasan, Crag 658, Zac and Cop-O-Zink alike, Zerlate, Tribasic and Robertson Copper alike, and check.

OHIO (Average of 4 locations). In descending order of disease control: Dithane D-14, and Parzate fungicide alike; Dithane Z-78; Parzate liquid; Cop-O-Zink; Crag 658; Zac; Methasan; COC-S; Robertson Copper; Zerlate; Tribasic; and check. In descending order of yield: Dithane D-14 and Parzate fungicide alike; Dithane Z-78, Parzate liquid; Zac; Methasan; Zerlate; Cop-O-Zink; Robertson Copper; COC-S and Tribasic alike; and check.

TOMATO

EARLY BLIGHT

ALABAMA (Fairhope and Tallassee). Control in descending order was: (1) Dithane Z-78 (10% dust); (2) Dithane Z-78 (5% dust); Dithane D-14; (3) Tribasic (6% dust). Tribasic gave best results at Fairhope and Z-78 (10%) at Tallassee. Overall preference was: (1) Dithane Z-78 (10%); (2) Dithane Z-78 (5%); (3) Tribasic (6%); (4) Dithane D-14 (decreased yield on spring tomatoes at Fairhope). Conditions not favorable to dusting in June and July because of frequent rains.

DELAWARE (Wyoming). Control in descending order was: (1) Zerlate-Parzate mix (1-1), Dithane Z-78-Bordeaux split schedule (3-2), Parzate-Bordeaux split schedule (3-2), Bordeaux, all given equal rank; (2) Parzate, Dithane Z-78; (3) Zerlate, Zerlate-Bordeaux split schedule (3-2), Parzate-Tribasic alternating schedule; (4) Tribasic, Zerlate-Tribasic alternating; (5) untreated. Bordeaux and fixed copper somewhat more injurious than other materials but less so than in previous years. Descending order of yields: (1) Parzate-Bordeaux, Dithane Z-78-Bordeaux, Zerlate-Bordeaux, Tribasic, all of equal rank; (2) Zerlate, Zerlate-Tribasic alternating, Parzate-Tribasic alternating schedule; (3) Parzate, Dithane Z-78, Parzate-Bordeaux. Overall preference: (1) Dithane Z-78-Bordeaux; Zerlate-Parzate mix; (2) Parzate, Dithane Z-78, Zerlate-Bordeaux, Parzate-Bordeaux. Season hot and dry.

ILLINOIS (Urbana). Descending order of control was: (1) Dithane Z-78, (2) manganese ethylene bisdithiocarbamate; (3) Zerlate-Tribasic mix (1-2), (4) Zerlate-Tribasic alternating; (5) Cop-O-Zink; (6) Methasan paste; (7) Tribasic; (8) Zerlate; (9) Bioquin plus Wettable Sulfur (1/4 + 3). Cooperator states that this last combination did not do as well as in 1948. Thought to be due to method of mixing. In 1948 slurries of each were prepared before putting in spray tank while in 1949 the two materials were shaken slowly into tank with agitator running. No apparent injury from any fungicide. Descending order of yield: (1) Zerlate-Tribasic mix; (2) Mn ethylene bisdithiocarbamate, (3) Dithane Z-78; (4) Methasan; (5) Zerlate-Tribasic alternating, (6) Zerlate; (7) Cop-O-Zink; (8) Bioquin 1 - Wettable Sulfur mix; (9) Tribasic. Overall preference: (1) Dithane Z-78, Zerlate-Tribasic mix, (2) Methasan paste, Mn ethylene bisdithio-carbamate, Zerlate-Tribasic alternating.

MARYLAND (Hurlock). Descending order of control was: (1) Zerlate-Tribasic alternating, (2) Copper oxide (Robertson); (3) Parzate, Bordeaux; (4) Dithane Z-78, Zerlate-Tribasic mix, Dithane Z-78-Bordeaux split schedule (2-3); (5) Zerlate-Tribasic split schedule (2-3), Copper 8-sulfur mix; (6) Tribasic, Cop-O-Zink. Descending order of plant safety: (1) Zerlate-Tribasic split schedule, Zerlate-Tribasic alternating, Zerlate-Tribasic mix, Copper 8-sulfur mix, (2) Tribasic, Dithane Z-78, Cop-O-Zink; (3) Bordeaux, Zerlate-Bordeaux split schedule; (4) Parzate. Descending order of yield: (1) Zerlate-Tribasic mix, Copper 8-sulfur mix; (2) Dithane Z-78, Bordeaux, Zerlate-Tribasic split schedule, Zerlate-Tribasic alternating, Zerlate-Bordeaux split schedule, Cop-O-Zink; (3) Tribasic, Parzate. Overall preference: (1) Zerlate-Tribasic split schedule, Zerlate-Tribasic alternating, Zerlate-Tribasic tank mix, Zerlate-Bordeaux split schedule; (2) Tribasic,

Dithane Z-78, Cop-O-Zink. Every application was followed by rain within 24 hours.

NORTH DAKOTA (Fargo). No disease in plots. Descending order of yield was: (1) Cuprocide, Cop-O-Zink; (2)Zerlate, Tribasic; (3) Dithane Z-78, Phygon. Phygon showed somewhat more plant injury than other materials tested. Overall preference Zerlate and possibly Cop-O-Zink.

TEXAS (Jacksonville). Owing to severe drought there was almost no damage from leaf or fruit diseases. Materials used were all applied as dusts and none appeared to cause visible injury to the plants. Descending order of yields was: (1) Rotenone .25% + piperonyl cyclonene .5% + pyrethrins .05%; (2) Methoxyclor-Copper A mixture; (3) White Diamond 63 X tomato dust; (4) Rogers C-D tomato dust; (5) Alltox-K Dust No. 10-63 Differences were slight in 1, 2, and 3. Yields with Alltox-K Dust No 10-63 were slightly better than the untreated check. No explanation of the increased yields was given.

EARLY BLIGHT AND LATE BLIGHT

VIRGINIA (Blacksburg). Materials applied as dusts. Rainfall heavy and frequent and late blight severe. Twelve applications of dusts were made whereas 6 to 8 usually are sufficient in season of normal rainfall. "All fungicides were effective in reducing the disease incidence and none caused injury to the plants or fruit." Descending order of yields was: (1) Parzate (20%); (2) Parzate (65%); (3) Robertson's Copper Fungicidal Dust; (4) Parzate (65%); (5) Tribasic. Overall preferences: (1) Parzate 20%, Robertson's Copper Dust; (2) Parzate (65%), Tribasic.

EARLY BLIGHT AND SEPTORIA LEAF SPOT

HAWAII (Maui). Descending order of control was: (1) Zerlate; (2) Dithane D-14-$ZnSO_4$ and lime; (3) Tribasic; (4) Parzate; (5) Yellow Cuprocide. Descending order of plant safety: (1) Zerlate, Parzate, Tribasic; (2) Yellow Cuprocide; (3) Dithane D-14. Descending order of yield: (1) Tribasic; (2) Zerlate, Parzate; (3) Dithane D-14. Overall preference: (1) Tribasic; (2) Zerlate; (3) Parzate.

ANTHRACNOSE

NEW JERSEY (New Brunswick). Season very dry and disease not severe. Materials tested were Tribasic, Bioquin, Crag 658, Phygon XL, Dithane D-14, Dithane Z-78, Parzate, Zerlate-Tribasic split schedule, Zerlate-Tribasic mix (1-2), Zerlate-Parzate mix (1-1), and Dithane Z-78-Bordeaux split schedule. No change in preference as result of this test. No significant difference in control by various fungicides. Disease in treated plots ranged from 1.3 to 7.5 percent with 6 to 9 percent in untreated plots. No evidence of plant injury and no significant differences in yield.

ILLINOIS (Urbana). Descending order of control was: (1) Methasan; (2) manganese ethylene bisdithiocarbamate; (3) Zerlate; (4) Dithane Z-78; (5) Zerlate-Tribasic alternating; (6) Zerlate-Tribasic (1-2) mix; (7) Tribasic; (8) Cop-O-Zink; (9) Bioquin-Wettable Sulfur mix. No evidence of

injury from any treatment. Descending order of yield: (1) Zerlate-Tribasic mix; (2) Mn-ethylene bisdithiocarbamate; (3) Dithane Z-78; (4) Methasan; (5) Zerlate-Tribasic alternating; (6) Zerlate; (7) Cop-O-Zink; (8) Bioquin 1-Wettable Sulfur mix; (9) Tribasic. Overall preference: (1) Dithane Z-78, Zerlate-Tribasic; (2) Methasan, Mn-ethylene bisdithiocarbamate, Zerlate-Tribasic; (3) Zerlate. (See comments under report on early blight).

NEW YORK (Geneva). In disease control the following treatments were grouped as the most effective: Zerlate-Bordeaux alternating, Zerlate plus Ortho K-Bordeaux alternating, Zerlate-Tribasic alternating, Zerlate-Parzate tank mix, Zerlate plus Ortho K-Parzate mix. The following treatments were inferior in disease control: Zerlate, Zerlate plus Ortho K, Methasan, Methasan plus Ortho K, Zerlate-Dithane Z-78 mix plus Ortho K, Dithane Z-78, Dithane Z-78 plus Ortho K, Dithane D-14 with $ZnSO_4$. No plant injury occurred with fungicides listed as most effective. Yield differences not significant. Overall preference: (1) Zerlate plus Ortho K-Bordeaux alternating; (2) Zerlate-Bordeaux alternating; (3) Zerlate-Tribasic mix; (4) Zerlate-Parzate mix, Zerlate-Parzate mix plus Ortho K. Season very dry and anthracnose only disease occurring to a measurable extent.

OHIO (Wooster). Descending order of anthracnose control by fungicides applied as sprays: (1) Mn ethylene bisdithiocarbamate; (2) Parzate + Mn ethylene bisdithiocarbamate; (3) Parzate; (4) Zerlate + Parzate; (5) Zerlate-Tribasic alternating; (6) Fungicide C; (7) Zerlate + p.e.p.s.; (8) Zerlate; (9) Zac S; (10) Zerlate + Florigel; (11) Methasan Bonded; (12) Dithane + $ZnSO_4$; (13) Dithane Z-78; (14) Methasan S; (15) Zerlate + F 529; (16) 5379, Fermate; (17) Zac S + Latex; (18) Crag 658; (19) Zac S + p.e.p.s.; (20) Calcium ethylene bisdithiocarbamate; (21) Zerlate + AS50; (22) Fac S; (23) COC-S; (24) Penn 492; Zerlate + Parzate alternating; (25) Zerlate + Latex; (26) Dithane Bonded; (27) Methasan; (28) 829B5G; (29) Parzate + $ZnSO_4$; (30) Tribasic, Robertson Copper; (31) 658B5G; (32) Esminel N; (33) Cop-O-Zink.

In this experiment soil around the plants was artificially contaminated with the causal organism of anthracnose fruit rot. Rot was severe and many treatments failed to give satisfactory control. Cooperator's note: "Even Zerlate, which can usually be depended upon to give between 75 and 80 percent control, did not reduce the rot by more than 60 percent. This was one of the few instances in the author's experience where Parzate (dry form) seemed to check anthracnose better than Zerlate, and a combination of Parzate and manganese ethylene bis dithiocarbamate gave very good results, although the latter material used alone did even better. Zerlate plus Parzate was also fairly effective. Cop-O-Zink, Esminel, Tribasic, some of the copper-zinc-chromate formulations, Fac S, and Robertson Copper gave comparatively poor control of this disease. Net yields were high with most of the Zerlate formulations, 'Manganese bis' and the alternating schedule of Tribasic and Zerlate. On the other hand, they (net yields) were somewhat low with most of the Dithane formulations, the Methasans and chromates, as well as the untreated checks. Some of these treatments that produced comparatively low yields gave better than average control of early blight -- which indicates that anthracnose was probably more important in determining the net yields of usable fruit than was defoliation

by early blight in this experiment. The fixed-copper plots rather generally had more green fruits remaining on the vines at the end of the picking season than did most of the organics, with the exception of 'manganese bis'."

Another series of treatments was sprayed on Rutgers plants at Wooster. Anthracnose was comparatively mild and defoliation from early blight did not affect yields until mid-September. Cooperator's note: "Anthracnose was best controlled by Zac, several Methasan formulations, Parzate, and Parzate plus 'Manganese bis'. It was comparatively severe on most of the fixed-copper and the copper-zinc-chromate plots, as is usually the case. 'Calcium bis' and Oilcop also gave little control of anthracnose. Early blight, as indicated by the percentage of defoliation, was best controlled by the fixed coppers and such materials as Dithane and Parzate. The percentage of culls was comparatively high with most of the copper-containing compounds, usually because of poor anthracnose control, but the average was slightly lower with the 'organics'. P.e.p.s. was used with six different fungicides in this experiment and brought about very little change in the various criteria used to indicate performance of the various treatments. Gross and net yields were slightly lower when p.e.p.s. was used. The percentage of culls and of fruits affected with anthracnose were lower (indicating slightly better disease control). The degree of defoliation was similar with or without p.e.p.s. but the green fruit yields were also slightly lower with p.e.p.s."

Several fungicides were applied as dusts to Rutgers tomatoes at Wooster. Descending order of anthracnose control was: (1) Methasan-Talc; (2) Zerlate-Talc; (3) Zac-Talc; (4) Dithane-Talc; (5) Tribasic-Talc; (6) untreated; (7) Parzate-Talc; (8) COC-S-Talc; (9) Crag 658. Cooperator's note: "Methasan gave the best control of the light infection of anthracnose which occurred, and also the lowest percentage of culls and the largest net yield. Crag 658 gave comparatively poor control of anthracnose but a good net yield. COC-S was also high in anthracnose but gave good control of early blight and the largest yield of green fruit at the end of the season. Dust formulations of this type have given surprisingly good disease control on tomatoes for the past two years."

OHIO (Fremont). An experiment on the control of anthracnose fruit rot and defoliation diseases was again conducted at Fremont. Late blight was very scarce and early blight and anthracnose were less prevalent than usual. Descending order of anthracnose fruit rot control was: (1) Methasan S; (2) Zerlate; (3) Zac; (4) Zerlate and Parzate alternating; (5) Crag 658, Zerlate-Parzate mix; (6) Parzate; (7) Tribasic; (8) Dithane. Cooperator's note: "Anthracnose was best controlled by Methasan, closely followed by Zerlate and Zac. Methasan and Zerlate were also comparatively low in percentage of culls. Net yields were highest with Dithane, Methasan, and the alternating schedule of Zerlate and Tribasic."

OHIO (Sandusky). This was a planting of Stokesdale tomatoes that produced an excellent crop. Cooperator's note: "Zerlate and Parzate, and an alternating schedule of the two, all were responsible for large gross and net yields. Zac S also did well in this respect. The best control of anthracnose was again furnished by Methasan, closely followed by Zerlate and Zac S. The same treatments were also comparatively low in culls,

although Tribasic gave the best results in this respect, which was somewhat surprising in view of the fact that it did not control anthracnose. However, a type of soil rot which was prevalent during the latter third of the picking season was best checked by Tribasic. The Methasan and Dithane plots showed the best foliage condition in this experiment near the end of a season when early and late blight were practically non-existent."

OHIO (Marietta). Several fungicides and 5 different insecticides were applied to staked tomatoes at Marietta. Yields were very much alike for all treatments. Descending order of early blight control on the basis of defoliation on August 12 was: (1) Tribasic-CS 645; (2) Tribasic-Marlate; COC-S with DDT-A; (3) Tribasic-Parathion; (4) Tribasic-Chlordane, Tribasic-Rhothane; (5) Cop-O-Zink and DDT-A; (6) Parzate-DDT-A; (7) Tribasic-DDT-A; (8) Zac-DDT-A, Robertson Copper-DDT-A; (9) Crag 658-DDT-A; (10) Methasan S-DDT-A; (11) Zerlate-DDT-A. Cooperator's note: "COC-S, of the fungicides, gave the best control of a rather heavy infection of early blight. Dithane, Tribasic and Cop-O-Zink also did well in this respect. Zerlate gave comparatively poor control of early blight, as did Methasan and Crag 658 in this experiment."

Cooperator's summary. "In general the results obtained with various fungicides tested in 1949 (which included most of those now available) indicate that zinc dimethyl dithiocarbamate (ziram) should still be depended upon for anthracnose control, and that a new material (manganese ethylene bis dithiocarbamate) may enter the picture for the control of this disease. The fixed coppers and the zinc ethylene bis dithiocarbamate (zineb) will usually give the best control of early blight (and possibly late blight too when it occurs). Also, there is planty of evidence that the alternating schedule of ziram with a copper or zineb should still be used for overall disease control on tomatoes."

LATE BLIGHT

NOVA SCOTIA (Kentville). Descending order of control was: (1) Zerlate (1 appl.) followed by Bordeaux (3 appl.); (2) Tribasic, Phygon, Bordeaux (10-7 1/2-100), Bordeaux (7-3 1/2-100), given equal rank; (3) Basicop dust. Descending order of safety: (1) Tribasic, Phygon, Basicop; (2) Zerlate-Bordeaux; (3) Bordeaux (10-7 1/2-100), Bordeaux (7-3 1/2-100). Descending order of yield: (1) Bordeaux (7-3 1/2-100); (2) Untreated; (3) Tribasic; (4) Basicop; (5) Zerlate-Bordeaux; (6) Phygon; (7) Bordeaux (10-7 1/2-100). Overall preference: (1) Zerlate-Bordeaux; (2) Tribasic, Phygon. Severe drought during July and August affected growth and blossom-end rot was prevalent. First late blight appeared in checks October 1. Last spray applied September 14 and trace of late blight found in all plots October 15. At that time checks showed 29.5% blight.

SOUTH CAROLINA (Charleston). Descending order of control was: (1) Tribasic, Cop-O-Zink; (2) Parzate, Dithane Z-78, Copper-zinc-chromate; (3) Zerlate. Cooperator's note: "All except Zerlate gave satisfactory control. The coppers appeared slightly superior to Dithane and Parzate." No injury from any treatment. Descending order of yield: (1) Tribasic, Cop-O-Zink; (2) Parzate, Dithane Z-78, Zerlate, Copper-zinc-chromate. Overall preference: (1) Tribasic; (2) Cop-O-Zink; (3) Parzate, Dithane Z-78, Cn-Zn-chromate. Late blight was severe during period of almost daily

showers from June 1 to 15. Dry weather retarded progress of the disease thereafter but crop was severely damaged.

GRAY LEAF SPOT (*Stemphylium solani*)

FLORIDA (Homestead, Dade Co.). Season unusually warm and dry. Descending order of control: (1) Dithane Z-78, Dithane D-14-$ZnSO_4$ and lime, Parzate Liquid-$ZnSO_4$ and lime, Dithane D-14-$ZnSO_4$, magnesium ethylene bisdithiocarbamate-$ZnSO_4$; (2) Dithane D-14-$ZnSO_4$ and lime alternated with Phygon XL; (3) Copper A (8 appl.) followed by Dithane D-14-$ZnSO_4$ and lime, Parzate; (4) CR 305, Phygon XL; (5) Copper A; (6) Copotox. Materials not providing commercial control were: Dithane D-14-$ZnSO_4$ and lime alternated with Phygon XL, CR 305, Copper A, Copotox, Phygon XL, and Parzate. All sprays containing zinc ethylene bisdithiocarbamate caused extensive yellowing and mottling after light frost of January 2, 1949, but plants were recovering within 10 days and later growth was normal. No other injury reported. Descending order of yield: (1) Dithane Z-78, Dithane D-14-zinc and lime, Parzate Liquid-$ZnSO_4$; (2) Dithane D-14-$ZnSO_4$ and lime, CR 305, Dithane D-14-$ZnSO_4$, magnesium ethylene bisdithiocarbamate; (3) Copper A followed by Dithane D-14-$ZnSO_4$ and lime, Copper A, Copotox, Phygon XL, Parzate. Overall preference: (1) Dithane Z-78, Dithane D-14-$ZnSO_4$ and lime, Parzate Liquid-$ZnSO_4$ and lime, Mg ethylene bisdithiocarbamate.

LATE BLIGHT AND BACTERIAL SPOT

FLORIDA (Homestead, Dade Co.). Season unusually warm and dry. Descending order of control of bacterial spot on fruit: (1) CuTMTD; (2) SR 406, Phygon XL alternated with Dithane D-14-$ZnSO_4$ and lime, Dithane D-14-$ZnSO_4$ and lime, Dithane D-14-$ZnSO_4$, Parzate Liquid-$ZnSO_4$; (3) Phygon XL, magnesium ethylene bisdithiocarbamate-$ZnSO_4$; (4) untreated; (5) CR 305. All fungicides controlled late blight with no evidence of difference between them. Descending order of yield (marketable fruit): (1) SR 406; (2) Phygon alternated with Dithane D-14-$ZnSO_4$ and lime, Mg ethylene bisdithiocarbamate-$ZnSO_4$, Phygon XL, CuTmTd, Dithane D-14-$ZnSO_4$ and lime; (3) Parzate Liquid-$ZnSO_4$; (4) CR 305. Overall preference: (1) Dithane D-14-$ZnSO_4$ and lime, Dithane D-14-$ZnSO_4$, and Parzate Liquid-$ZnSO_4$.

BUCKEYE ROT (*Phytophthora parasitica*)

TENNESSEE (Knoxville). Conditions very favorable for development of buckeye rot. Materials tested were: C-O-C-S plus Resyn Adhesive #3605 and Tribasic plus Resyn Adhesive #3605. Both gave good control without evident injury to plants. Yields were satisfactory with both fungicides. No preference indicated.

POLE BEANS (BLUE LAKE)

WHITE MOLD (*Sclerotinia sclerotiorum*)

OREGON. Descending order of control was: (1) Zerlate dust 10% and Zerlate (1:100) + sulfur (4-100); (2) Flotox; (3) Zerlate (1.5-100) and

Bismuth subsalycilate (1-100) and ditto 6% dust, and Sulforon and C.O.C.S. + Kolodust 20-80; (4) Zerlate 10% dust + sulfur 90% dust and Kolodust. No injury. No yield data. No preference can be stated yet but Zerlate or Zerlate plus sulfur combination show greatest promise.

LIMA BEANS (HENDERSON BUSH)

DOWNY MILDEW

DELAWARE (Bridgeville). Descending order of control: (1) Bordeaux (6-6-100) and Tribasic (3-100) and Parzate dust 6%; (2) Dithane Z-78 (2-100); (3) Parzate (2-100); (4) Dithane Z-78 dust 6% and Tribasic dust 10%; (5) untreated. Descending order of yield: (1) Tribasic dust, (2) Parzate (2-100) and untreated; (3) Tribasic (3-100); (4) Parzate dust; (5) Dithane Z-78 (2-100); (6) Bordeaux 6-6-100; (7) Dithane Z-78 dust. Preference: Tribasic dust 10%. Injury from Bordeaux; slight to moderate injury from Tribasic.

DELAWARE (Milton). Descending order of control: (1) Tribasic dust 10%; (2) Bordeaux (6-6-100); (3) Tribasic (2-100); (4) Parzate dust 6%; (5) Dithane Z-78 (2-100); (6) Parzate (2-100); (7) Dithane Z-78 dust 6%; (8) untreated. Descending order of yield: (1) Dithane Z-78 dust; (2) Tribasic dust; (3) Dithane Z-78; (4) Bordeaux and Parzate dust; (5) Tribasic; (6) Parzate; (7) untreated. Preference: Tribasic dust 10%. Injury from Bordeaux; slight to moderate from Tribasic.

PEPPER

FRUIT ROTS

MARYLAND. Descending order of control: (1) Dithane Z-78 (2-100); (2) Tribasic (4-100); (3) untreated. No injury observed. Order of preference same as above.

PEAS

FUSARIUM WILT

COLORADO. Variety, Early Alaska. Fungicides were applied as dusts on soil along row, worked into soil and watered well; 2 applications, 1 week apart. All used at rate of 2 1/2 lb./100 sq. ft. Descending order of control: (1) Dithane Z-78; (2) Parzate; (3) Zerlate; (4) Spergon (wettable) and Fermate; (5) untreated. Descending order of yield; Dithane Z-78; Zerlate; Parzate; Spergon; Fermate and untreated. Overall prefence same as order of control.

CELERY

LATE BLIGHT (Septoria)

OREGON. Variety was Pascal. Appl. schedule 7 day. Descending order of control: (1) Tribasic (4-100), Parzate (1.5-100), Phygon (0.75-100),

Zerlate (1.5-100), Tribasic dust 7%, Parzate dust 10%, Zerlate dust 10%; (2) Actidione (3 ppm). Phygon XL caused stunting and chlorosis; Parzate some chlorosis. Descending order of preference: (1) Tribasic, Zerlate, Tribasic dust, Zerlate dust; (2) Parzate, Parzate dust; (3) Phygon; (4) Actidione.

EARLY BLIGHT (Cercospora)

MICHIGAN. Appl. weekly beginning early July. Season favorable for early blight; unfavorable for late blight. Descending order of control, plant safety, yield and preference: (1) Dithane Z-78 6% + 30% sulfur; (2) Cuprocide 6% + 30% sulfur; (3) Tribasic + 30% sulfur + Nu-Z; (4) Tribasic + 30% sulfur.

OHIO. Appl. schedule 6 day. Descending order of control: (1) Methasan Slurry (3-100); (2) Zerlate (2-100), Tribasic (4-100); (3) Dithane Z-78 (2-100); (4) Parzate (2-100); (5) Cop-O-Zink (4-100); (6) untreated. Descending order of yield, trimmed celery: (1) Methasan slurry, (2) Dithane Z-78, (3) Zerlate, Parzate; (4) Tribasic; (5) Cop-O-Zink (6) untreated.

ONTARIO. Variety, Golden Phenomenal. Appl. schedule 7 day. Descending order of disease control: (1) Bordeaux (4-4-40), Copper oxide (3.5-100), and C.O.C.S. (7.5-100); (2) SR-406 (2-100), CR-305 (2.5-100); (3) Phygon XL (1-100); (4) untreated.

CARROTS

YELLOWS AND LEAF SPOTS

OHIO. Appl. 9 day schedule. Descending order of disease control: (1) Tribasic (4-100); (2) Tribasic + DDT (4-2-100); (3) Crag 658 + DDT (2-2-100); (4) Parzate + DDT (2-2-100); (5) Zerlate + DDT (2-2-100); (6) Dithane Z-78 + DDT (2-2-100); (7) untreated. Descending order of yield; (1) Tribasic; (2) Crag 658; (3) Zerlate + DDT, Parzate + DDT; (4) Dithane Z-78, Tribasic + DDT; (5) untreated.

STORAGE ROTS (Botrytis and Sclerotinia)

IDAHO. Fungicides dusted on roots in storage. Descending order of control: (1) Arasan (15%); (2) Arasan (15%) + Fermate (15%); (3) Fermate (15%); (4) Fermate (100%); (5) untreated; (6) Borax (15%). Borax caused injury. Preference: (1) Fermate (15%); (2) Arasan (15%).

ONION

DOWNY MILDEW

MICHIGAN. Dusting schedule weekly from July 10. No mildew developed in plots. Descending order of yield, plant safety and preference: (1) Dithane Z-78 6% + sulfur 30%; (2) Tribasic 25% + sulfur 30% + nuzinc; (3) Cuprocide 6% + sulfur 30%. Zinc and sulfur stimulated yield.

OREGON. Dusting schedule: after rains, 8 appl., March 19-May 2.

Descending order of control, yield and preference. Test No. 2. (1) Dithane Z-78 (8%) + DDT (3%); (2) Copper (7%) + mineral oil (2%) + DDT (3%). Test No. 1. Following all failed to give disease control under severe conditions of test: Copper (7%) + zinc (1.5%) + DDT (3%); Cuprocide 7% + sulfur 30% + DDT (3%); Copper (7%) + mineral oil (2%) + zinc (1.5%); Copper (7%) + DDT (5%) + celite (2.5%) + diluex (1%).

PURPLE BLOTCH

COLORADO. Spray every 10-14 days. Triton B1956 spreader and Goodrite P.E.P.S. sticker used with both fungicides. No significant difference in control, yield, or preference between Yellow Cuprocide (1.5-100) and Dithane Z-78 (1.5-100). Both good.

GENERAL

OHIO. Sprays on 10-day schedule; all contained DDT for thrips control at rate of 2-100. Descending order of yield: (1) Parzate (2-100); (2) Dithane Z-78 (2-100); (3) Crag 658 (2-100); (4) Zac (2-100); (5) Zerlate (2-100); (6) C.O.C.S. (2-100); (7) untreated.

SPINACH

DOWNY MILDEW

CALIFORNIA. Weekly sprays. Order of control, yield and preference: (1) Dithane Z-78 (1.5-100); (2) Rosin lime-sulfur (1 gal. each-100).

WASHINGTON. Sprays and dusts, 4 appl. at weekly intervals beginning first leaf stage. Descending order control: (1) Spergon dust (6%), Dithane D-14 (2 qt.) + zinc sulfate 1 lb.-100; (2) Phygon dust (2%), Tribasic (4-100); (3) Amm. Copper Carb. (55%) (6 oz.-3 pts.-50); (4) Spergon wettable (3-100), Phygon XL (0.5-100), SW XP 41A 5 ppm; (5) untreated. Descending order of preference: (1) Dithane D-14, Spergon dust; (2) Tribasic; (3) Amm. Copper Carb., Spergon spray, Phygon dust; (4) Phygon XL and SW XP 41A.

CUCUMBER

DOWNY MILDEW

NORTH CAROLINA. Dusted at 10-day intervals and after each rain in excess of 0.25 in. Descending order of yield: (1) Tribasic (5%); (2) Parzate (10%); (3) Dithane Z-78 (10%); (4) Zerlate (10%); (5) untreated. No injury observed. Preferred treatment, Tribasic.

SOUTH CAROLINA. Nine appl. at 7-day intervals on 3 mildew-resistant varieties. Sprays 80-100 gal./A, 800 gal. total; dusts 12-30 lb./A, 170 lb. total. Descending order of control: (1) Dithane Z-78 (1.5-100); (2) Zerlate (2-100), Dithane Z-78 dust (8%); (3) Tribasic (3-100), Cu-Zn-Chromate (2-100), Cop-O-Zink (3-100); (4) Zerlate dust (8%), Tribasic dust (10%), Cu-Zn-Chromate dust (8%), Parzate liquid + Zinc sulfate (2-3/4-100); (6) untreated. No injury from any noted. Descending order of yield:

(1) Dithane Z-78 spray; (2) Dithane Z-78 dust, Zerlate spray; (3) Tribasic, Cu-Zn-Chromate, Zerlate dust; (4) Cop-O-Zink, Tribasic dust; (5) Cu-Zn-Chromate dust, untreated; (6) Cop-O-Zink dust, Parzate dust, Parzate liquid. Sprays preferred to dusts. Overall first choice Dithane Z-78 spray.

DOWNY MILDEW AND ANTHRACNOSE

LOUISIANA. Dust -- ten appl. 4-6 day intervals. Variety Cubit. Descending order of control of downy mildew: (1) Dithane Z-78 (8%), Cop-O-Zink (7%), Tribasic (7%), #658 (8%), SR-406 (8%); (2) Parzate (8%), Fermate (8%). Descending order of control of Anthracnose: (1) Fermate (8%), Dithane Z-78 (8%), Parzate (8%); (2) SR-406 (8%); (3) #658 (8%); (4) Tribasic (7%), Cop-O-Zink (7%). Tribasic and Cop-O-Zink caused slight marginal chlorosis which plants outgrew. Order of preference: (1) Fermate, Dithane Z-78, Parzate; (2) SR-406; (3) #658; (4) Tribasic, Cop-O-Zink.

SCAB (Cladosporium)

MICHIGAN. Var. National Pickling. Sprayed 7 times July 7-September 1 incl. Descending order of control and preference: (1) Actidione (10 ppm); (2) Cu-Zn-Chromate(2-100); (3) Tribasic (3-100); (4) Dithane Z-78 (2-100); (5) Zerlate (2-100) and untreated. Descending order of total (clean, cull, scab) yield: (1) Dithane Z-78; (2) Cu-Zn-Chromate (3) untreated; (4) Zerlate; (5) Actidione; (6) Tribasic. Very slight marginal chlorosis from both copper materials. Zerlate ineffective in scab control.

CANTALOUPE (MUSKMELON)

DOWNY MILDEW AND MACROSPORIUM LEAF SPOT

NEW JERSEY. Sprays -- 3 appl. 9-day intervals. Disease control poor. Descending order of disease control (Downy mildew): (1) Crag 658 (4-100), Tribasic (4-100) M-294 (3-100); (2) Dithane D-14 + zinc sulfate (2 qt.-1-100), Dithane Z-78 (2-100), SR-406 (4-100); (3) SR-406 (2-100), Fermate (2-100), Zerlate (2-100). Inorganic coppers caused yellowing of leaf margins. Preferred materials, Dithane Z-78 and Tribasic.

DELAWARE. Variety - Halis Best Jumbo. Eight appl. July 1-August 18 incl. Descending order of control (Macrosporium): (1) Bordeaux (6-3-100), Yellow Cuprocide (1.5-100), Dithane Z-78 (2-100) 5 appl. followed by Bordeaux (6-3-100) 3 appl.; (2) Tribasic (3-100) Parzate (2-100), Dithane Z-78 (2-100), Dithane D-14 + Zn sulfate (2-1-100), Parzate liquid + Zn sulfate (2-3/4-100), Zerlate-Parzate 1-1 (2-100), Copper A (3.5-100); (3) Tribasic dust (10%) Zerlate dust (10%), Dithane Z-78 dust (6%), Crag 658 (2-100), Copper A dust (10%); (4) Zerlate (2-100), Parzate dust (6%); (5) untreated. Parzate and Dithane caused yellowing and bronzing of foliage; copper sprays caused less injury than in previous years when weather was cooler and wetter. Descending order of yield: (1) Tribasic dust, Zerlate dust, Parzate dust, Dithane Z-78 dust, Dithane D-14, Crag 658, Dithane Z-78-Bordeaux split; (2) Yellow Cuprocide, Tribasic, Zerlate, Parzate, Dithane Z-78, Liquid Parzate, Zerlate-Parzate (1-1), Copper A and Copper A dust; (3) untreated; (4) Bordeaux.

Preferred first choice: Tribasic, Dithane Z-78, Dithane Z-78-Bordeaux split schedule.

MARYLAND. Variety - Halis Best Jumbo. Five appl. July 1-August 12 incl. Descending order of control (Downy mildew and Macrosporium): (1) Bordeaux (6-3-100); (2) Tribasic (4-100); (3) Dithane Z-78 (2-100); (4) Zerlate (2-100). Descending order of plant safety: (1) Zerlate; (2) Dithane Z-78, (3) Tribasic; (4) Bordeaux. Descending order of yield: (1) Tribasic, (2) Bordeaux, Zerlate; (3) Dithane Z-78; (4) untreated. Order of preference: (1) Tribasic; (2) Zerlate; (3) Dithane Z-78; (4) Bordeaux.

SOUTH CAROLINA. Variety - Halis Best Jumbo. Dusted 7 times May 30-June 29 incl. Descending order of control (Downy mildew): (1) Dithane Z-78 (8%); (2) Zerlate (8%); (3) Parzate (8%); (4) Tribasic (10%). Descending order of yield: (1) Zerlate; (2) Dithane Z-78; (3) Parzate; (4) Tribasic. Order of preference: (1) Dithane Z-78, Zerlate; (2) Parzate, Tribasic. None of the fungicides gave adequate protection due to numerous showers. Tribasic caused slight injury early in season.

MICHIGAN. Variety - Purdue 44. Sprayed 7 times July 7-September 1 incl. No disease developed though inoculated with Macrosporium and Colletotrichum 3 times. Marginal yellowing caused by Tribasic and Cu-Zn-Chromate. Injury not reported for Actidione, Dithane Z-78, Zerlate.

WATERMELON

DOWNY MILDEW

FLORIDA. Variety, Cannon Ball. Dusted 10-day interval. Descending order of control: (1) Tribasic (7%), (2) Dithane Z-78 (8%), Zerlate (8%); (3) Parzate (8%); (4) #658 (8%); (5) Tribasic (7%) + bentonite; (6) Copper oxide (8%). Order of plant safety: (1) Dithane Z-78; (2) Tribasic, Zerlate; (3) Parzate #658. Yield not available. Zerlate increased aphid damage. Parzate caused burning of foliage. Tribasic and #658 gave typical copper burning of foliage, but not serious. Preferred materials: (1) Dithane Z-78; (2) Tribasic.

FLORIDA. Variety Cannon Ball. Sprayed every 7 days. Descending order of control: (1) Tribasic (4-100); (2) Dithane Z-78 (2-100); (3) Dithane D-14 + Zn sulfate (2-1-100); (4) Parzate (2-100); (5) Parzate liquid + Zn sulfate (2-1-100). Yield not taken. Tribasic burned foliage. Dithane better than Parzate; Dithane Z-78 better than D-14. No injury from Parzate or Parzate liquid. Preferred material: Dithane Z-78.

GUMMY STEM BLIGHT

FLORIDA. Variety, Cannon Ball. Sprayed every 7 days. Descending order of control: (1) Dithane Z-78 (2-100); (2) Dithane D-14 + Zn sulfate (2-1-100); (3) Tribasic (4-100). Latter failed to control disease. Order of plant safety same as above. Preferred fungicide: Dithane Z-78.

VALUE OF THE NEWER FUNGICIDES FOR VEGETABLE DISEASE CONTROL

The excellent performance of the zineb materials on a wide range of vegetable crops was again demonstrated. One or more of them were effective in the control of the following diseases: early and late blights, and anthracnose of tomato; early and late blights of potato; downy mildews of lima beans, onion, spinach, cucumbers, and watermelons; early blight of celery; cucumber anthracnose; pepper fruit rot; Macrosporium leaf spot of cantaloupe; and gummy stem blight of watermelons. Parzate was reported to have caused some chlorosis in celery, burned watermelon foliage, and caused a yellowing and bronzing of cantaloupe foliage.

ACTIDIONE. Good control of cucumber scab in one test.

BIOQUIN 1. Wettable sulfur mixture gave excellent control of early blight in one instance and failed in another trial.

COPPER-ZINC-CHROMATES. Look good for Macrosporium leaf spot of cantaloupe and promising for early and late blights of potatoes, and for cucumber scab. One of them caused a marginal yellowing of cantaloupe foliage.

COP-O-ZINK. Looks promising for downy mildew of cucumber and early and late blights of potato. Caused slight marginal burn on cucumber in one test. On tomatoes it performed unevenly but was quite effective against early and late blight in a few instances.

CR 305. Did not show great promise in a single test against gray leaf spot of tomato but in another test it gave satisfactory control of late blight.

FERMATE. Was good for cucumber anthracnose.

MAGNESIUM ETHYLENE BIS DITHIOCARBAMATE. Proved very effective against potato and tomato early blights and against tomato anthracnose.

MANGANESE ETHYLENE BIS DITHIOCARBAMATE. Was effective against potato and tomato early blights and against tomato anthracnose.

PERENOX. Looked promising in one test on potato late blight.

PHYGON XL. When used alone or in combination with Dithane D-14 did not give outstanding disease control on tomatoes but it was promising in one test on potato late blight. It caused stunting and chlorosis in celery.

ROBERTSON'S COPPER. Seemed to be ineffective against early and late blights of tomatoes and early blight of potatoes but tests were limited.

SPERGON DUST. Looks good for downy mildew of spinach.

ZIRAM. Materials look good for early and late blight of celery and when used alone or in combination with copper fungicides they were effective against tomato anthracnose and early blight. Tank mixtures of Zerlate-Parzate and Zerlate-Tribasic also gave good results on tomatoes where tested. Zerlate was ineffective for cucumber scab and one report from Florida stated that it increased aphid damage on watermelon.

RESULTS WITH ORNAMENTAL CROPS, TURF SHADE TREES AND SHRUBS

AZALEAS

PETAL BLIGHT: ALABAMA. Dithane D-14 + zinc sulfate + lime, Dithane Z-78, Parzate, and Parzate liquid were equally effective. Parzate dust and Dithane Z-78 dust were slightly less effective and had a tendency to be injurious. Crag Potato Fungicide # 658 and Actidione were not effective. Bloomocide was also ineffective and caused necrotic spotting. Reduced concentrations of Dithane D-14-zinc and lime were as effective as the normally recommended concentration, but lower concentrations of Parzate and Dithane Z-78 were less effective. Three applications a week during the flowering period gave the best control, two applications were satisfactory and one application per week was insufficient. There was no injury with Parzate but Dithane D-14, Dithane Z-78, and Parzate liquid resulted in wilting and burning of the flowers when the plants were suffering from a lack of water.

CARNATION

ALTERNARIA LEAFSPOT AND BRANCH ROT: NEW YORK (Farmingdale). Bioquin 1 again gave the best control followed by SR-406, CR-305, Zerlate, Crag Potato Fungicide, Actidione, and Fulex B in that order. B-1956 spreader was used with all materials. Crag Potato Fungicide caused slight injury. Injury with SR-406 was doubtful. Zerlate is recommended because of its lower cost.

FUSARIUM ROOT ROT: COLORADO. Control in descending order of efficacy was as follows: Fulex B, Dithane Z-78, Carbide and Carbon 531, Carbide and Carbon 658, and Goodrite Z.A.C. Ceresan M and Calogreen were not effective. Dithane Z-78 was given over-all preference because there was no plant injury. Ceresan M and Calogreen caused excessive stunting and hardening of the young plants. Flower yields were poor when C & C 531 and C & C 658 were used. Spore suspensions of Trichoderma lignorum gave control about equal to that of Dithane Z-78 but spore suspensions of Aspergillus flavus had no effect.

BACTERIAL LEAF SPOT AND RUST: HAWAII. Five materials were tested. Tribasic copper sulfate and Yellow Cuprocide were effective against bacterial leaf spot but not against rust whereas Zerlate, Fermate, and Dithane D-14 were effective against rust but not against bacterial leaf spot. Dithane D-14 caused stunting of the plants and a marked reduction in flower yield. Yellowing of the leaves occurred during bright, warm periods when Yellow Cuprocide was used.

CHRYSANTHEMUM

FOLIAR NEMATODE: NEW YORK. Control was nearly perfect with 25% wettable parathion at both Ithaca and Farmingdale. Poorer control was obtained with 20% parathion emulsion at Ithaca. Chlordane, TEPP, Lindane, and Black Leaf 40 were much less effective and did not give practical control. Chlordane gave fair control when used at 4 lbs. per 100 gallons but it left an objectionable residue.

SEPTORIA LEAF SPOT: NEW YORK. (Ithaca). Parzate (spray or dust), 549C (spray or dust), SR-406, Bioquin 1, or Fermate all gave equally good control followed closely by Crag Potato Fungicide and by Goodrite Z.A.C. CR-305 was also good. Actidione gave the poorest control of all fungicides tried. The ferbam materials remain first choice because of consistent apparent superiority in plant vigor and color.

GLADIOLUS

FUSARIUM ROT: ILLINOIS, MARYLAND, NEW YORK (Ithaca), NEW YORK, (Farmingdale), NORTH CAROLINA, OHIO, ONTARIO. In a cooperative test using a single variety from one source, Arasan Ceresan M, Dow F-800, Dow 9B, Dowicide B, Lysol, mercuric chloride, New Improved Ceresan, and Puraturf 177 were compared with no treatment. Puraturf 177 was not effective in any location. There were fewer rotted corms when Dow F-800 was used but yields were variable. In Ohio and Ontario flower and corm yields in the Dow F-800 plots were less than the untreated, whereas in the other areas they were significantly greater. Flower yields were also less than the untreated at Ithaca. Mercuric chloride also reduced flower yields but not corm yields in North Carolina. Arasan Ceresan M, Dow 9B, Dowicide B, Lysol, and New Improved Ceresan all resulted in greater flower and corm yields in at least 3 locations

FLORIDA: New Improved Ceresan, Dow 9B, Spergon, Natriphene, N-N, 36L, and PMA were compared in preplanting treatments. Results with the last three were not sufficiently good to merit further testing. Best control was with New Improved Ceresan and with Dow 9B. Wettable Spergon and Natriphene gave equal control and caused least injury. Equal over-all preference was given to New Improved Ceresan and Spergon followed by Dow 9B and Natriphene.

ILLINOIS: Thirteen materials were tested on six varieties. New Improved Ceresan, mercuric chloride plus New Improved Ceresan, Dowicide B, Dow 9B (dip or dust), Dow F-800, and Seedox 50 controlled Fusarium rot about equally well. Puraturf 177 and Puratized Agricultural Spray (as a dust) were ineffective. Ceresan M, Lysol, Arasan and Tag 331 were fairly effective In two other tests pre-storage treatments were tried. In one, Arasan and Phygon increased the number of rot-free corms and in the other Dow F-800 was very effective with Phygon less effective, but both injured the bases of the corms. Arasan was not effective in the second test.

SCAB: The corms used in the cooperative test mentioned above were from one source, but after a season's growth in the different locations the percent of scabby corms in the untreated varied from 5.3 to 62.2 and corm treatments for scab control did not appear to be effective in any location.

ILLINOIS. The following were compared on corms of seven varieties: mercuric chloride, 2-hour soak; mercuric chloride, 14-hour soak; mercuric chloride plus New Improved Ceresan, 30-minute soak; sulfur applied in the furrow before planting; and lime applied in the furrow before planting. The long soaks were most effective and the short soaks and the combination treatments were much less effective. Sulfur and lime each increased scab slightly.

LEAF SPOTS: FLORIDA. Spray compatibility tests were made with 5 fungicides and 4 insecticides. No disease or insects were involved. DDT, chlordane, and Toxaphene were each tested in combination with Dithane D-14-zinc sulfate, Dithane D-14-zinc sulfate-lime, Parzate, or with calcium liquid Parzate-zinc sulfate. Yields were not affected by any of the fungicides in combination with DDT or Toxaphene but yields were reduced when they were in combination with chlordane.

IRIS

FUSARIUM BASAL ROT: WASHINGTON. Equally good control was obtained with hot water-formalin plus Ceresan M, or plus Ceresan M combined with Tersan, or plus Tersan, or with Aretan alone. All of the hot water-formalin treatments caused injury because the bulbs were treated two weeks too late. Aretan was also injurious. Next best control was obtained with either of the following: Mersolite 8, Tersan plus Ceresan M, Tersan, or Ceresan M. Lime-sulfur was ineffective. Ceresan M was preferred and better control was obtained when bulbs were treated August 26 than when treated just before planting October 2.

NARCISSUS

FUSARIUM BASAL ROT: MARYLAND. In one experiment begun in 1945 and concluded in 1949 using the same bulbs and same treatments for 4 years, New Improved Ceresan and Mersolite 8 gave the best rot control followed by Arasan, Spergon, Tersan and Puratized Agricultural Spray. Fermate was not effective. Bulb yields were best with New Improved Ceresan followed by Spergon. New Improved Ceresan caused flower injury. In an experiment begun in 1946 and concluded in 1949, New Improved Ceresan, 2% Ceresan, Arasan, Mersolite 8 and Puratized Agricultural Spray all gave good rot control in each of the three years but the first two materials caused severe flower injury. Dowicide B gave good rot control but delayed flowering and injured the flowers; rot control was poor with Roccal, Copper 8, and Carbide and Carbon 341; and thiourea caused flower injury. Arasan SF, Mersolite P, Dow 9B and New Improved Ceresan gave good rot control for two years in a test begun in 1947. Bulb yields were best with the first three. Rot control was poor with Wettable Spergon, Puratized 177, bismuth subsalicylate, or Parzate.

WASHINGTON. Rot control was good when bulbs were dipped in solutions containing Mersolite 8 or Mersolite 8 plus Dioxane. Mersolite 8 dissolved in Carbitol before adding to the water was ineffective in controlling the rot.

ROSE

BLACK SPOT: ARKANSAS. Equal control was obtained with fungicides containing copper, ferbam, or sulfur. Injury was least with the copper treatment and greatest with the sulfur treatment. The ferbam material was Du Pont Rose Dust, the sulfur a 90:10 sulfur-lead arsenate mixture, and the copper was 4 parts Tennessee Corporation tribasic copper sulfate (26% Cu), 4 parts Nu-Z (55% zinc), 4 parts lead arsenate, 4 parts Armour sticker, 86 parts talc.

NEW YORK (Ithaca). Good control was obtained with manganese ethylene bis dithiocarbamate (either as a spray or as a dust), J. & P. Rose Spray, colloidal copper-white oil emulsion, Tag 331, Tag 331 plus wettable sulfur. Bioquin 1, Bouisol, COCS dust, Crag Fruit Fungicide 341C, and SR 406 gave fair control, and CR 305 and Rix both gave poor control. Rix and colloidal copper-white oil emulsion each caused severe burning. Bioquin 1, J. & P. Rose Spray, Tag 331 plus sulfur, and Crag Fruit Fungicide 341 C each caused slight burning during hot weather. Manganese ethylene bis dithiocarbamate as a spray was best from an over-all viewpoint because it gave good control, did not burn and left no unsightly residue.

MILDEW: NEW JERSEY. Control of mildew on Mme. Joseph Perrand roses out-of-doors was best with Bordeaux 2-4-100, Tribasic copper, Parzate, Puratized Agricultural Spray, and Bioquin 1. It was poor with Fermate, and fair with SR 406 or Crag 341 C. Bordeaux and tribasic copper each caused severe leaf burn, and Puratized Agricultural Spray caused slight necrotic spotting in midsummer. Parzate, SR 406, Crag 341 C, and Bioquin 1 were given equal over-all preference.

SNAPDRAGON

RUST: NEW YORK (Ithaca). Rust control was in the following descending order: Parzate (spray or dust), Fermate, 549 C (spray), Goodrite Z.A.C., 549 C (dust), CR 305, SR 406, Bioquin 1, Actidione, and Crag Potato Fungicide. The first gave near-perfect control and the last was no better than the untreated. Crag Potato Fungicide was quite toxic to the foliage, and CR 305 injured plants under some conditions. Plants sprayed with Parzate were slightly paler. Bioquin 1 gave poor control of rust but good control of secondary invaders and consequently plants sprayed with Bioquin 1 looked good from a distance.

TULIP

BOTRYTIS: WASHINGTON. Good control of primary "fireheads" was obtained when bulbs were soaked in water containing Aretan before planting. No control was obtained when bulbs were soaked in water containing Semesan Bel, Wettable Spergon, or Fermate. Aretan, and to a lesser extent Semesan Bel, reduced flower height, caused some blasting, and also decreased the yields of bulbs harvested. Spergon-or Fermate-treated bulbs frequently yield better than other bulbs for some unexplained reason.

TURF

BROWN PATCH. In a cooperative test with Bent grasses in four states (Iowa, Massachusetts, Rhode Island, and New Jersey) Calochor was most effective followed by PMAS, Spergon W and Tersan. Results were fair with Puraturf and Puraturf G-G and poor with Cadminate and Crag 531. Merck H258 T was ineffective. Temporary yellowing after each application occurred with PMAS and Puraturf in New Jersey and Rhode Island. Severe burning occurred with PMAS and Calochor in Massachusetts whereas Calochor caused only slight injury in Rhode Island and New Jersey.

DOLLAR SPOT. In a similar test in six states (California, Iowa, Massachusetts, Pennsylvania, Indiana and Rhode Island) Puraturf 177 and

Crag 531 gave the best results followed by Cadminate, Puraturf G-G, Calochor, Merck H258 T, PMAS, and Puraturf in that order. Spergon W and Tersan were not effective. Temporary yellowing following applications of PMAS or Puraturf occurred in California, Indiana and Rhode Island. PMAS caused severe burning in Massachusetts and Calochor caused burning in both Massachusetts and Rhode Island.

HELMINTHOSPORIUM LEAF SPOT RHODE ISLAND. Puraturf gave complete, and PMAS nearly complete, control. Cadminate, Puraturf G-G, and Calochor were nearly as effective whereas Crag 531, Merck H 258 T, Puraturf 177, Spergon W, and Tersan were much less effective.

SHADE TREES AND SHRUBS

HOLLY (*Ilex opaca*) NEW JERSEY. Severe leaf burn and defoliation occurred with Bordeaux at 4-4-100, at 2-4-100, and even at 1-4-100 in the summer. This is particularly important since publications on holly suggest "try Bordeaux for foliage diseases". Severe burn and defoliation also occurred with Tribasic copper at 4-100, 2-100 and 1-100. Puratized Agricultural Spray caused some slight chlorotic ring-spotting. Fermate, SR 406 and Parzate did not cause injury and the best foliage color occurred where the first two were used.

FUNGICIDES TESTED ON SHADE TREES IN ILLINOIS[1]

Fungicide tested	SHADE TREES						
	Black walnut	Elm, American	Ulmus parvifolia	Ulmus pumila	Norway maple	Hard maple	Sycamore
Arathane WP-25	+	+	+	+	+	+	+
Bioquin 1							+
Bordeaux + zinc sulfate	+	+					
Carbide and Carbon #5379	+		+	+	+	+	
Crag Fruit Fungicide 341 C	+	+	+				
Crag Potato Fungicide 658		+				+	
CR 305	+	+	+	+	+	+	
Cupreous Powder No. 3005	+	+	+		+		+
Fermate	+	+			+		+
Goodrite Z.A.C.		+	+			+	
L-658		+					
Manganese ethylene bis dithio-carbamate		+	+	+	+	+	+
Parzate		+				+	+
Puratized Agricultural spray	+	+	+		+		+
Puratized Apple Spray	+	+	+	+	+	+	+
Puraturf GG	+	+					
Tag Fungicide # 331	+	+	+	+	+	+	+
Zerlate		+					

FUNGICIDES TESTED ON SHADE TREES IN ILLINOIS (continued)

Fungicide tested	SHADE TREES							
	Linden	Mountain Ash	White Ash	Catalpa	Red Oak	Hack-berry	Honey Locust	Russian Olive
Arathane WP-25	+	+	+	+	+	+	+	+
Bicquin 1								
Bordeaux + zinc sulfate								
Carbide and Carbon #5379	+	+	+	+	+	+	+	+
Crag Fruit Fungicide 341 C								
Crag Potato Fungicide 658								
CR 305	+	+	+	+	+	+	+	+
Cupreous Powder No. 3005								
Fermate			+					
Goodrite Z.A.C.								
L-658								
Manganese ethylene bis dithio-carbamate								
Parzate								
Puratized Agricultural spray			+					
Puratized Apple Spray	+	+	+	+	+			
Puraturf GG			+	+	+	+		
Tag Fungicide # 331	+	+	+	+	+	+	+	+
Zerlate								

[1]Because of dry weather, leafspot diseases on the shade trees listed were insufficient to give control data. Of the materials tested only Fermate caused injury and this was only on the underside of black walnut leaves.

EFFECTIVENESS OF MATERIALS ON ORNAMENTALS

ACTIDIONE. Tested for control of azalea blight, mum Septoria, snapdragon rust and ineffective for all.

ARETAN. A Dutch mercury product and looks good for bulb treatments for controlling Fusarium rot of iris and fire of tulips.

BIOQUIN 1. Good control of Alternaria on carnations but Zerlate recommended because it is cheaper. Also looks good for Septoria on mums. Only fair for rose blackspot but promising for mildew. Gave poor rust control on snapdragons but good control of secondary organisms and plants looked good from a distance.

BORDEAUX. Caused serious injury to holly foliage in spite of fact publications say "Try Bordeaux mixture for holly leafspot control."

CR 305. Looks promising for Alternaria on carnations, fair for snapdragon rust and was no good for rose blackspot.

CRAG 341 C. Fair for mildew and blackspot on roses.

CRAG POTATO FUNGICIDE 658. No good for snapdragon rust or azalea petal blight.

DOW F-800. Looks good for control of Septoria leafspot of mums.

GOODRITE Z.A.C. Looks promising for carnation rust.

MANGANESE ETHYLENE BIS DITHIOCARBAMATE. Very promising for control of blackspot of roses.

PARATHION. One of the most striking results were those of Dimock and Ford in controlling mum leaf nematodes with spray applications.

PURATURF 177. Not effective for controlling Fusarium rots of gladiolus or narcissus.

RIX. No good for rose blackspot and caused injury.

SR 406. Fair for mildew and blackspot on roses and snapdragon rust, promising for Alternaria on carnations and Septoria on mums.

549 C. Looks good for control of Septoria leafspot of mums.

GENERAL. Superiority of carbamate materials again demonstrated in controlling azalea petal blight, rust on carnations and snapdragons, and Septoria on mums.

The cadmium-containing fungicides, Cadminate, Crag 531, and Puraturf 177, were superior for the control of dollar spot of turf. The organic phenyl materials also gave control but were not so effective. The cadmium materials were of little value for brown patch of turf.

RESULTS WITH TOBACCO AND SPECIAL CROPS

TOBACCO

BLUE MOLD

GEORGIA (Tifton). Most growers used ferbam sprays (4-100) or dusts (15%) with excellent results. Those few growers using ferbam-salicylic acid spray (1-100) or zineb dust (10%) likewise obtained excellent control. It is estimated that 85% of growers used sprays or dusts.

FLORIDA (Gainesville). A mild attack was noted during plant-growing season with a heavy attack on plants after transplanting to the field. In tests very satisfactory results were obtained with Fermate (ferbam) dust (15%), Parzate (zineb) dust (10%) and Fermate-salicylic acid spray.

FLORIDA (Quincy). Yields of seedlings per square yard and preferential rating in descending order were Dithane Z-78, 262; Parzate, 249; Fermate 183; and check, 137. No injury was noted from any of these fungicides.

STAGHORN SUMAC

FUSARIUM WILT

COLORADO (Ft. Collins). Dithane Z-78 (5 lbs./100 sq. ft.) and copper sulfate (2 1/2 lbs./100 sq. ft.) were applied once to the plant bed soil with hand duster and garden hose, respectively. Dithane Z-78 gave the best control and was the preferred treatment. Both were equally safe.

RESULTS WITH SOIL FUMIGATION AND DRENCH TESTS

In tests at Windsor, Connecticut, Iscobrome D at 30 gal. per acre, Dowfume W-40 at 15 gal. per A, and DD at 30 gal. per A were applied to the soil with a tractor-drawn shank applicator ten days before setting tobacco plants. Most effective control of meadow nematode was obtained with Dowfume W-40 and Iscobrome D.

In tests at Oxford, North Carolina, propylene oxide (40 cc. per sq. yd.), Iscobrome D (255 cc. per sq. yd.) and chloropicrin (38 cc. per sq. yd.) were applied with a sprinkling can, and methyl bromide (1 lb. per 10 sq. yds.) was applied with a gas applicator to soil of tobacco plant beds. The time of application in relation to sowing of tobacco seed was not stated. The methyl bromide gas was rated first in control of meadow nematode (black shank), Iscobrome D and chloropicrin second, whereas propylene controlled weeds but not the nematode. None controlled nematodes, however, unless the fumes were confined, sisalkraft paper being used for this purpose.

In tests at Florence, South Carolina, Dowfume W-40 and DD were applied to tobacco fields at 5, 10, and 15 gal. per A in row treatments and 20 and 30 gal. per A in broadcast treatments. The time of treatment in relation to setting of the tobacco plants is not stated. Though all dosages increased yield, the 30 gal. per A dosage of both materials was most effective against root-knot and meadow nematode. At this dosage neither material proved the superior. With both, the maximum effect on nematode was obtained when the soil was packed after treatment. Dowfume W-40 was less agreeable to handle and gave indications of retaining a residual effect in the soil longer than DD. Because of an adverse effect on the quality of the cured product, however, the general use of such soil fumigants on flue-cured tobacco lands was not recommended.

In tests at Quincy, Florida, Dowfume W-40 at 15 gal. per A and DD at 20 gal. per A were tested against the root-knot nematode in tobacco soils. In one test the fumigants were applied for the second consecutive season. Treatments were given to different plots on October 8, 1948; November 30, 1948; and February 4, 1949. Judging from the root-knot index, the timing of the Dowfume treatment did not affect control. With DD, however, apparently the November and February treatments were more effective than the October treatment. All treatments of both materials increased the yield of tobacco, the earlier treatments more than the later ones. In a second test, DD and Dowfume W-40 treatments were given on December 16, 1948 for the third consecutive season. Here the more effective control and higher yield was obtained with Dowfume.

In tests at Gainesville, Florida, Dowfume W-40 and DD were applied in drill rows at the rate of 8 to 10 gallons per A 5 weeks before tobacco plants were set in the rows. This method of treatment is said to be as effective as broadcast application and cheaper. In order to avoid introducing nematode-infested soil into the treated area, fertilizer was placed along the side of the drill rows at the time of fumigation treatment. Though these materials gave only a moderate control of root-knot nematode, the yield of tobacco was increased by treatment. Neither material proved superior in this respect. The quality of the tobacco, on the other hand,

was reduced by the DD treatment.

In tests at Elba, New York, 300, 400, 450, and 500 lbs. per A of DD and 180, 220 and 260 lbs. per A of Dowfume W-40 were applied for control of bulb and stem nematode (bloat) of onions. One treatment was given in autumn before spring sowing, a tractor-drawn shank-type applicator being used. Neither of the dosages of Dowfume employed controlled the nematodes. With DD, the 450 and 500 lb. per A dosages gave the best control but proved more injurious to the plants than the 300 lb. dosage.

CONTROL OF FUSARIUM ROOT ROT

OF PEAS WITH FUMIGANTS

In tests at Geneva, New York, one treatment of Larvacide at 104 gal. per A, Dowfume G at 260 gal. per A, and Dowfume N at 130 gal. per A was given 12 days before peas (Thomas Laxton) were planted. Larvacide gave control of root-rot caused by _Fusarium solani_ var. _martii_; the other materials were ineffective. None, however, are recommended for control of this disease.

RESULTS WITH SEED TREATMENTS

Forms for reporting the relative merits of seed treatment materials, as determined by tests on seeds of various crops, were sent to 86 workers in agricultural experiment stations and colleges in the United States and Canada in the fall of 1949. Twenty persons responded by returning the forms filled out with the information requested. Ten others replied that no such information was available because no tests had been made. The remaining 56 failed to indicate any interest in the work of this committee.

The 21 replies received represent the cooperative effort of about 46 workers in 24 States and 4 Canadian Provinces in testing 50 materials on seed of one or more of 17 agricultural crops. The data on most of these crops, however, are too meagre to serve as a basis for making definite recommendations. They are summarized in table 1.

BARLEY

Reports from Canada representing experiments at 6 stations in 3 provinces indicate that Ceresan M, Panogen (8 and 14), and Leytosan are the favored standard treatments for the control of covered smut and blight (Helminthosporium sativum). The experimental materials M.T.H. and R 118-A were effective in some tests. In experiments with winter barley carried out at 9 stations in the Southeast, the mercurials, Panogen 14, and the Ceresans, eliminated covered smut with 1.4 to 15.3 percent in the controls, and also stripe-disease with 3 to 18 percent in the controls. Fairly good smut control was obtained also with the non-mercurial organics, Phygon, Spergon and Arasan, although these materials are not generally recommended for barley because they were ineffective against stripe disease.

Similar results were obtained at 10 stations in the spring-barley area. The Ceresans (1/2-ounce), Panogen 14 (1.5 ounce), Phygon (1 ounce), and Arasan (2 ounces) eliminated covered smut in Odessa barley with from 7 to 20 percent in the controls. Panogen 14 at 3/4 ounce per bushel was not completely effective. Dow 9-B and Seedox, both at 2 ounces per bushel were relatively ineffective. Stripe disease was eliminated by the Ceresans and reduced to less than 1 percent by Panogen 14 (1.5 ounce), with 8 to 15 percent in the controls. Phygon reduced infection to 5 percent or less.

OATS

In Kansas, Ceresan M and Panogen 14 reduced the percentage of smut infection to 0.5 and 1.7 percent respectively, while 74 percent appeared in the controls. These materials also improved emergence in oat varieties susceptible to Victoriae blight but not in resistant varieties.

In Ontario a modified form of Agrosan was rated superior to Panogen 14 and 8 in improving emergence and combating Helminthosporium victoriae. In tests at three stations in Manitoba, Panogen, Ceresan M, and Leytosan were rated best among 8 materials with respect to their effect on stand of mature plants and also on control of Victoriae blight.

In cooperative tests at 6 stations in the Southeast, loose and covered smuts were completely eliminated by the Ceresans and by Panogen 14, while

Table 1. Summary of Seed Treatment Reports for 1949

Seed Treated	Location of Experiments: Provinces	Location of Experiments: States	Reports received	Materials tested	Best Results from*
	Number	Number	Number	Number	
Barley	3	17	4	14	Ceresan, Panogen, Leytosan
Wheat	3	17	5	16	Ceresan, Panogen, Anti carie
Corn	-	7	4	10	Arasan, Phygon L224, Spergon
Rice	-	3	4	10	Ceresan M, Arasan, Spergon Phygon, Cuprocide, K.F. 467
Sorghum	-	2	2	20	Arasan, Phygon, Panogen Ceresan M, Spergon
Flax	2	5	2	9	Ceresan M, Panogen, M.T.H.
Cotton	-	1	1	4	Seedox, Ceresan M, Dow 9-B
Peanuts	-	1	1	7	Arasan, Phygon, Spergon
Clover	-	1	1	3	Arasan
Alfalfa	-	1	1	3	No benefits
Peas	-	6	4	10	L-640, Spergon, Arasan, L224, KF 460
Beans	-	5	3	13	Arasan, Spergon, 5400, L-640, 531
Tomatoes	-	4	2	7	Cuprocide, L-640, 854, Arasan
Cucurbits	-	3	2	10	N. I. Ceresan, Semesan, Arasan, 5400, 854
Cabbage	-	2	1	6	Arasan, L-224, Semesan, 5400
Spinach		4	1	6	854, 5400, Arasan, L-640
Beets		3	1	6	Arasan, 5400, 854

* Not always listed in order of effectiveness.

from 8 to 22 percent appeared in the controls. Spergon, Phygon, Arasan and Seedox were highly unsatisfactory. At 10 Western stations satisfactory smut control was obtained with the Ceresans (1/2 ounce) and Panogen 14 (1.5 ounce) with 16 to 45 percent infection in the controls. Phygon, Arasan, Seedox and Dow 9-B were unsatisfactory.

WHEAT

In Kansas, with 78 percent infection in plots from untreated seed, the Ceresans at 1/2 ounce and M.T.H. at 1 ounce per bushel eliminated bunt, while Arasan, Phygon and Spergon, all at 2 ounces per bushel, reduced it to 1.5, 1.2 and 0.8 percent respectively. Mercan was totally ineffective. At 6 stations in the eastern winter wheat area, bunt in wheat was eliminated by the Ceresans and Panogen 14 and reduced to less than 1 percent by Spergon, Phygon and Arasan. At 10 stations in the Western spring-wheat area, similar results were obtained with these materials. Dow 9-B and Seedox were unsatisfactory. At Beltsville, Maryland, none of these materials caused any significant increase in yield when applied to clean disease-free seed of Purplestraw wheat.

At Pullman, Washington, the Ceresans were best in bunt control in Idaed and Elgin wheats. Phygon paste 1-500, Spergon, chromate L-224 and chromate 640 were inferior and Parson's Seed Saver Dust was highly unsatisfactory. At 6 stations in Canada the percent of bunt infection ranged from 26 to 81 percent and averaged 45 percent. Anti carie at 3/4 ounce per bushel gave the best control of bunt. Next in order of effectiveness were Panogen 14, (1 oz.), Ceresan M (1/2 oz.), Leytosan (3/4 oz.), and Benesan (3 oz.).

CORN

Reports were received on experiments in Iowa, Illinois, Wisconsin, New York, New Jersey, Ohio, and Florida.

In Illinois, Arasan, Spergon, and Phygon, in the order named, were most effective in increasing yields of corn hybrids U.S. 13 and Ill. 972. K.F. 467 and L-224 were only slightly less effective.

In Wisconsin, Arasan S. F. at 1 ounce per bushel was found best for corn. Slightly heavier slurry applications were more effective but were difficult to apply. Phygon was almost as effective as Arasan, while Spergon was rated somewhat inferior.

In Iowa, L-224 (zinc mercury chromate) was rated as good as, or better than any other treatment. No. 854, No. 5400 and Arasan were nearly as good. Panogen 14 applied at 2 1/2 ounces per bushel (excessive) caused injury to corn in storage. In cooperative experiments in New York, New Jersey, Florida and Ohio, L-224 seemed to maintain its lead as the best treatment, with 854, 5400 and Arasan sharing second place, and L-640 and Spergon in third place.

RICE

Only four reports on rice seed treatment were received. At Stuttgart, Arkansas, five treatments were rated as follows with respect to

their effect on stands of Zenith and Blue bonnet rice: Ceresan M (1/2 oz. per bushel), Arasan (1.5 oz.), Dow 9-B (1.5 oz.), Phygon XL (1.5 oz.) and Yellow Cuprocide (1 oz.). Yellow Cuprocide, however, was considered the best treatment for rice sown in water.

In experiments at Beaumont, Texas, Ceresan M was rated best on Bluebonnet seed, with Arasan and Spergon second, and Yellow Cuprocide third. On Rexoro rice, Spergon was rated best, with Arasan second, and Ceresan M third. Dow 9-B was found to cause injury to stored Rexoro seed. Cuprocide, it was found, may cause injury to pre-sprouted seed.

At Crowley, Louisiana, seed of Magnolia rice was soaked in water for 24 hours after treatment, held moist for 24 hours and then water-planted with continuous flooding. None of the treatments increased germination but all except Arasan and K.F.-467 improved stands. Yellow Cuprocide (2 and 4 oz.), Tribasic copper (4 oz.), and No. 640 were rated about equally beneficial.

In tests with drilled seed of Bluebonnet rice, K.F. 467 was rated best in improving stands, Spergon was second and Phygon XL and Ceresan M third. In general, these materials along with Arasan were rated about equal for treating drilled seed of this variety.

SORGHUM

Among 15 materials applied to seed of Bonita, Sooner milo and Plainsman at Chillicothe, Texas, Arasan was most effective in improving field emergence while Spergon was almost as good. These were followed closely in effectiveness by Coppercarb, Zerlate, Fermate, Parzate, 2 percent Ceresan, and Phygon. Data on disease control were not recorded.

In emergence tests at Beltsville, Maryland, at 20° and 25°C., results were rather erratic, especially with Leoti sorgo. In general, Phygon, Panogen 14 and Arasan were most beneficial to emergence in Leoti and, along with copper carbonate, also in Sharon kafir.

Perfect control of covered kernel smut in both varieties was obtained with Phygon dust (2 oz.), Ceresan M (1/2 oz. dust and slurry), Panogen 14 (3/4 oz.) and Aagrano (1/2 oz.). Spergon (2 oz.), Arasan (2 oz.), Phygon slurry (2 oz.), and copper carbonate (2 oz.) eliminated smut in kafir but not in Leoti because of its persistent glumes. Infection in the kafir and Leoti checks was 29 and 46 percent respectively.

FLAX

In Minnesota, seed of three flax varieties, Crystal, Sheyenne, and B-5128, was commercially treated with Panogen (the older 1.2 percent product) at 3 fluid ounces per bushel. Samples of treated and untreated seed were stored in the laboratory for 10 months. The three lots of treated seed, in the order named, germinated 93, 87.5 and 46.4 percent respectively, better than the corresponding untreated controls. Portions of the three samples of untreated stored seed were then treated with Semesan Jr. (1 percent ethyl mercury phosphate) by the excess method and planted a day later along with untreated seed. Emergence from the treated samples was 50, 25, and 40 percent respectively better than from the three corresponding untreated seed lots.

Seed of Crystal flax was treated with Panogen 14 at rates of 3/16, 3/8, 3/4, 1 1/2, 3, 6 and 12 fluid ounces per bushel. In paper towels, germination was 100 percent and 55 percent at the 6 and 12 ounce rates respectively. In sterilized soil, the highest germination, 95 percent, followed the 3-ounce rate of treatment, with 60 and 35 percent at the 6 and 12-ounce rates respectively.

Panogen 14, applied to seed of Dakota, Crystal, and Minerva flax at 1 1/2 ounces per bushel increased the yield in field plots 15 percent, while N.I. Ceresan and Ceresan M applied at the same rate each increased yields 28.4 percent.

In cooperative experiments at 10 stations in Canada and the United States, flax seed rot, aggravated largely by a high percentage of cracked seed, was combatted most effectively by Ceresan M (1 1/2 oz.), Panogen 8 (3 1/2 oz.), Panogen 14 (1 1/2 oz.), and M.T.H. (2 oz.).

OTHER CROPS

COTTON

One report from North Carolina rated Seedox at 1.5 ounces per bushel as the preferred treatment for combatting seedling diseases. Ceresan M at 1 ounce per bushel (dust or slurry) and Dow 9-B at 1.5 ounces (dust or slurry) shared second place.

CLOVER AND ALFALA

A report from Illinois indicated some significant increases in germination and also prevention of damping-off in sweet clover and common white clover following treatment of seed with Arasan and Ceresan at the rather heavy rate of 2.4 to 4.8 ounces per bushel. Heavier applications caused injury. No benefit and some injury followed similar treatment of red clover seed.

Treatment of alfalfa seed with Arasan, Ceresan and Phygon resulted in no benefits to stands.

PEANUTS

One report from Alabama rated Arasan as best for combatting seed rot and damping-off in runner peanuts, with Phygon second and Spergon third.

PEAS

In Maryland, Arasan and Spergon were rated best for Pride peas. In cooperative experiments at six stations in four states, L-640 was rated best for emergence, and L-224 second.

In Wisconsin MF 468 was best for damping-off control followed by Phygon, Spergon, Arasan, Dow 9-B, and Phygon XL in that order. Arasan SF gave poor results.

BEANS

In Colorado No. 531, a calcium-zinc-copper-chromate complex, was rated best for Pinto beans with Goodrite second. In a three-State cooperative experiment, Arasan, 5400, L-640, 854, Spergon, and L-224 were rated equally effective. 5400 was rated best for lima beans with Arasan second and Spergon third.

TOMATOES

A report from Jacksonville, Texas, recommended Yellow Cuprocide as a safe and effective treatment for tomato seed. Cooperative experiments in New York, New Jersey and Florida rated L-640 and 854 as best for improving emergence with 5400 and Arasan second. Spergon and L-224 were rated ineffective.

CUCURBITS

At Norfolk, Virginia, Arasan (1/8 percent by weight) was best for emergence in cantaloupes while N.I. Ceresan (1/4 percent) proved best for watermelons. For cucumbers, Semesan seemed slightly better than Arasan, N.I. Ceresan, mercuric chloride (1-1000 for 10 minutes) or Cuprocide, although the differences were not significant. In cooperative tests in New York and New Jersey, No. 5400 was rated best for emergence in melons with No. 854, Spergon, Arasan, No. L-640 and No. L-224 next in order of effectiveness.

CABBAGE

At three stations in New York and New Jersey, Arasan and L-224 were rated best for improving emergence in two varieties of cabbage, with Semesan, 5400, 854, and L-640 following in order of effectiveness.

SPINACH

Emergence tests on seed of four varieties of spinach were carried out at six stations in New York, New Jersey, Ohio and Florida. The three materials, 854, 5400 and Arasan, were rated about equal in improving emergence, with L-640 and L-224 rated second in effectiveness, and Spergon third.

BEETS

Emergence from seed of Detroit Dark Red Garden beets in tests at six stations in four States was improved most by Arasan, and next in order of effectiveness were 5400, 854, L-640 and L-224.

GENERAL APPRAISAL OF FUNGICIDES FOR SEED TREATMENT

Only about 20 of the 50 materials tested as seed treatment, are standard commercial products now being manufactured and sold on the

American market for that purpose. Most of the other materials are still somewhat in the experimental stage, or are products that are generally intended for other purposes, such as control of foliage diseases or insects, fumigation of the soil or general disinfection. The more commonly used seed disinfectants and protectants mentioned are listed below, along with their chief uses.

ANTICARIE. For seed of wheat; sold in Canada for the control of bunt in wheat.

ARASAN (dust or slurry). For seed of corn, peanut, flax, sorghum, legumes, grasses, sugar beet, and most vegetables.

NEW IMPROVED CERESAN. For seed of barley, flax, oats, and wheat. It is being replaced to a great extent by Ceresan M.

CERESAN M (dust or slurry). For seed of barley, flax, oats, rice, sorghum, wheat, sugar beet, cotton, tomato, and some forage crops and vegetables. At present, it is probably the best material on the American market for cereal seed treatment.

COPPER CARBONATE. For seed of wheat and sorghum.

CUPROCIDE (Yellow). For seed of celery, carrot, pea, spinach, squash, beets, cucumber, egg plant, melon, pepper, chard, tomato, and other vegetables. It is likely to injure seed of lettuce, crucifers, and onion.

DOW 9-B. For seed of cotton, peanut, pea, rice, and some vegetables.

FERMATE. For seeds of pea, onion, cabbage, and lettuce, and for potato and sweet potato. Used largely as a foliage fungicide.

FORMALDEHYDE. For preventing onion smut by applying it to furrow with seed. Also for seed of beet, celery, wheat, oats, barley, and some other seeds when better materials are not available.

LEYTOSAN. For seed of barley, flax, oats, and wheat. Sold in Canada.

PANOGEN. For seed of barley, flax, oats, sorghum, wheat, and sugar beets. Its frequent changes in composition have retarded its general acceptance.

PHYGON XL (dust or slurry). For seed of corn, sorghum, rice, wheat, sugarbeet, peanut, pea, bean, and a number of vegetables.

SEEDOX. For seed of cotton. Not suitable for cereals.

SEMESAN (dust or soak). For seed of most vegetables and flowers.

SPERGON (dust or slurry, with or without DDT). For seed of corn, rice, sorghum, wheat, peanut, pea, bean, and most vegetables.

OTHER MATERIALS. A considerable number of unnamed experimental materials, usually referred to by numbers, were tested on seeds of several crops. L-224 is promising on seed of corn, peas, cabbage, beans, and several other vegetables. In experiments with vegetables, 5400, 531, 854, and L-640 also were fairly effective at times. These materials should be tested more extensively. K.F. 467, R118-A, Agrosan, Aagrano, and Mercuran also looked promising in some reports, but more extensive tests are needed to truly evaluate their effectiveness.

GENERAL. In general, Ceresan M continues to be the most widely used commercially available treatment for cereals, and is used rather extensively on some other crops. Arasan, Phygon, and Spergon continue as the principal materials for treating seed corn, although other compounds are on the way up. Vegetable seed treatment commercially is very similar to what it was a year ago as few, if any, outstanding fungicides have been placed on the market during that time.

The seed treatment situation in Canada is very ably summarized in the following statement by Dr. J. E. Machacek, plant pathologist at the University of Manitoba:

> "Seed treatment occupies a prominent place in Canadian agriculture. About half of our grain farmers treat their seed grain annually. Custom treating (by elevators, etc.) is very limited. Examination of seed for disease by certain industrial laboratories in Western Canada provides information regarding the need for treatment. Ceresan M, and Half-ounce Leytosan are the principal mercurials in use, chiefly as dusts. The new fluid treatments, Panogen 8 and Panogen 14, are receiving favorable comment but the cost of the applicator is still too high for the average farmer. The French non-mercurial dust, Anticarie SD, is expected to find only limited use owing to its limited control of disease. It is recommended for use against bunt (stinking smut) of wheat. Formaldehyde, in spite of recommendations against its use, is still comparatively popular with farmers."

THE PLANT DISEASE REPORTER

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Division of Mycology and Disease Survey

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SUPPLEMENT 193

PLANT DISEASE LOSSES: THEIR APPRAISAL AND INTERPRETATION

Supplement 193 June 15, 1950

The Plant Disease Reporter is issued as a service to plant pathologists throughout the United States. It contains reports, summaries, observations, and comments submitted voluntarily by qualified observers. These reports often are in the form of suggestions, queries, and opinions, frequently purely tentative, offered for consideration or discussion rather than as matters of established fact. In accepting and publishing this material the Division of Mycology and Disease Survey serves merely as an informational clearing house. It does not assume responsibility for the subject matter.

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PLANT DISEASE REPORTER SUPPLEMENT

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THE PLANT DISEASE SURVEY
DIVISION OF MYCOLOGY AND DISEASE SURVEY

Plant Industry Station Beltsville, Maryland

PLANT DISEASE LOSSES: THEIR APPRAISAL AND INTERPRETATION

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Plant Disease Reporter
Supplement 193 June 15, 1950

FOREWORD

Paul R. Miller

The Plant Disease Survey is glad to publish Dr. Chester's fundamental analysis of importance, principles, problems, and techniques of plant disease appraisal. This sort of contribution to plant pathology is a special interest of the Survey since it is of such immediate concern to our objectives. We should like to have been responsible for the preparation of this work ourselves; however, Dr. Chester has probably achieved greater objectivity than we could have and thus has been more effective in his presentation.

Our expression of interest in this work does not mean necessarily that we are in agreement with all its viewpoints. In spite of minor differences of opinion, however, we are fully convinced that such a handbook of disease appraisal, its significance and applications, has long been needed, and will be of great use to plant pathologists.

Most of this manuscript was completed while Dr. Chester was head of the Department of Botany and Plant Pathology at Oklahoma Agricultural and Mechanical College, Stillwater, Oklahoma. Inasmuch as Dr. Chester was then a collaborator of the Plant Disease Survey, and since our collaborators are considered an official and essential part of the Survey organization, we feel that its publication as a Supplement to the _Plant Disease Reporter_ is especially appropriate.

PROLOGUE

"It will be necessary for agriculture to become better informed on the extent and nature of all of its losses before much progress can be made toward reducing them."

--R. C. NEWTON, 1945.

"Apart from its purely scientific interest, accurate determination of the loss caused by a given disease offers the only safe guide in a rational policy of control."

--E. P. MEINECKE, 1928.

"How can we expect practical men to be properly impressed with the importance of our work and to vote large sums of money for its support when in place of facts we have only vague guesses to give them and when we do not take the trouble to make careful estimates? Determination of loss is a difficult and complicated matter, but I believe that we should seriously attempt it. We should develop quantitative methods, and make careful counts in restricted areas. I believe the accumulation of reasonably accurate data on losses will ensure us the attention of the public as will no other argument. . . . . The preparation of reliable and comprehensive estimates for even a few of the more serious plant diseases would be of immense educational value to the public and would tend to increase the support given all plant disease work."

--G. R. LYMAN, 1918.

"It is too bad that so many have contributed so little to this very important subject."

--W. D. MOORE, 1945.

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THE VALUE OF ACCURATE INFORMATION ON PLANT DISEASE LOSSES

INTRODUCTION: -- Because plant diseases cause economic loss and consequent hardship to society the science of plant pathology exists with the objective of preventing such loss. The funds upon which the science depends, whether public, industrial, or private, are almost invariably assigned with the understanding that they shall be used in research, education, and regulation designed to reduce the economic burden which plant diseases impose on the producers and users of agricultural commodities. Rare indeed is the plant pathologist who can say with Aristaeus: "From studying what are called maladies, I have come to consider them as necessary forms of life. I take more pleasure in studying them than in combating them."

Organized plant pathology may be compared with organized detection and prevention of crime. Imagine, for a moment, a crime-regulatory organization in which little is known of the comparative importance of different violations, in which the efforts of the police in detection and the judgments of the court are hampered by a lack of knowledge of which crimes are felonies and which are misdemeanors. The most glaring and odious crimes would be detected and appropriately punished, but there might be many cases when a spectacular crime of light import would detract the attention of police from more serious but less obvious crimes. On apprehension, the forcefully crude but petty thief might be judged with great severity, while the more subtle and more dangerous embezzler or large-scale swindler might escape with little effort at prevention of his future operations.

Unthinkable as such a situation would be in modern society, we have its counterpart in modern agriculture. We have little exact information on the relative destructiveness of diseases of crop plants or livestock, or of numerous other agricultural hazards, on which we might base the most effective and economical program of loss prevention. In plant pathology in particular, apart from the exceptional case of forest decay appraisal, our information on absolute and relative losses from plant disease is fragmentary and often demonstrably in error. As a result, our efforts in crop disease control have frequently been directed against diseases of lesser economic significance while others of greater destructiveness have received little attention. The case of potato latent mosaic is a striking illustration of this misplaced emphasis.

Potato latent mosaic, discovered and called "healthy potato virus" in 1925, is present in practically every potato plant grown in America, except new seedlings. Not for 20 years was its damage measured and found to average 13% of the crop, a figure confirmed by independent loss measurements in America, Australia, Scotland, and England. This measured amount of loss from latent mosaic is twice as great as the average annual loss from potato late blight (Phytophthora infestans), Rhizoctonia, and scab (Streptomyces scabies) combined, and four times the annual average loss from late blight, according to estimates of losses from these other diseases in the Plant Disease Reporter from 1919-1939.

Applying this figure, 13% loss, to American potato production during those 20 years, latent mosaic has caused a total loss of 1.1 billion bushels of potatoes. The bases for control of this disease by seed certification and varietal resistance have been available for many years. If the damage from latent mosaic had been measured and recognized when the disease was first discovered, if research on its control had been immediately undertaken, and if no more than one-tenth of this loss had been averted as a result, the gain would have amounted to 110 million bushels of potatoes with a value dwarfing to insignificance the cost of the research involved.

A similar situation has prevailed in the related sciences of human and veterinary medicine. In the former case, mortality statistics have, at last, effectively revealed the relative destructiveness of human ailments. Overpublicized minor diseases, such as leprosy, have been relegated to the background, while previously neglected major diseases, such as heart and kidney affections, are beginning to receive attention commensurate with their importance. In veterinary medicine, a start has been made toward determining, on a national scale, the relative destructiveness of livestock diseases.

A comprehensive study of the comparative losses from plant diseases is long overdue. Such a study has three aspects: (a) standardized, reasonably accurate appraisal of disease intensity; (b) translation of disease intensity into crop loss in terms of production units; and (c) interpretation of the impact of this crop loss on human welfare.

This book is primarily concerned with the first two of these aspects of the problem; the third, which is in the domain of economics and sociology, is considered only briefly.

PLANT DISEASE APPRAISAL AS A SERVICE: -- The determination of the occurrence, intensity, and destructiveness of plant diseases, though essential, is not an end in itself. It may be compared with the intelligence service of a modern army. Through extensive observations and probings, it uncovers the position, strength, and potentialities for destruction of the enemy, -- in this case, the agents of crop disease. Guided by this intelligence, and only so, the strength of the army can be applied at the most strategic points; in our case, research, education, and regulatory efforts can be applied mainly to those plant disease problems where the limited personnel and facilities can accomplish the most economic good.

There are three stages in the development of an adequate understanding of the extent and effects of crop losses: first, the development, by research, of standardized methods of loss appraisal and conversion factors which translate a given intensity of disease into loss percentage; second, well-planned surveys to apply these methods on a sufficiently broad scale to give a reliable picture of disease loss over a broad area; and third, summation, analysis, and interpretation of the survey data to determine the economic significance of plant disease losses.

The plant disease survey is an essential part of the activity, but it must be based on appraisal research, and its results must be subjected to economic interpretation if the survey is to attain the full measure of its usefulness as a service to other agricultural activities. Surveys in the past have frequently been deficient, first, in lacking an accurate experimental basis for disease appraisal and, second, as a result of this, in yielding data that are incomplete, non-uniform, and difficult to interpret in terms of economics. This may be a chief reason for the lack of interest in the support of surveys that has characterized the policies of some agricultural agencies.

Surveys are justified and valuable insofar as their results are of service to agricultural "action programs". If surveys rest on a sound scientific basis developed through appraisal research, and if their findings give a reliable, concrete, comparative picture of relative and absolute losses, the survey findings can be of immeasurable value in a wide variety of agricultural activities, as seen in the following examples.

THE USES OF ACCURATE DATA ON PLANT DISEASE LOSSES: -- Each of the major phases of agricultural science, research, education, regulation, various "action programs", and agricultural economics, can benefit in an important degree from the availability of accurate data on plant disease losses.

Some plant diseases are spectacular, but with relatively little economic significance; others subtly destroy unsuspected and important fractions of crops. The percentage of loss from disease which may be disregarded, economically, varies widely from one crop to another, and, in a single crop, from one disease to another, depending on the nature of the loss and the existence or lack of economical control measures. NEIL STEVENS (1938), in dealing with growers, advises: "If your loss is less than X%, forget it!" But, we must know the value of X in each case. Knowing it, and the significance of values greater than X, we can proceed intelligently and economically in each of the several agricultural activities that contribute to the reduction of wastage and unnecessary loss in crop production and utilization.

PLANNING AND DIRECTION OF AGRICULTURAL RESEARCH: -- The curtailment of scientific graduate training during World War II and the absorption of an increasing number of plant pathologists and mycologists into industrial and military research, make it mandatory that the work of the depleted and inadequate ranks of these scientists be directed at the most strategic points in the war against plant disease. As a nation with a moral and practical obligation to provide large sections of the world with agricultural necessities, we cannot afford to waste our limited scientific manpower by expenditure of research effort on problems of less economic and social singificance while more critical problems are being neglected. Accurate comparative information on plant disease losses and their effects is the necessary guide to the most efficient use of our resource of research ability.

How do agricultural research projects originate? Why is one problem selected in preference to others? Many factors are involved: personal preferences; availability of men with specialized interests or training; physical facilities; pressures from grower-groups or others; and restricted permissible uses of research funds; but, most frequent is the apparent importance of the problem. Rarely is this apparent importance verified by comparative study of the many lines of possible research; indeed, it is frequently impossible to make such a study, -- the data on which to base it do not exist.

The apparent importance of a problem may be far from its true relative importance. Problems appear to be important when they are well publicized; when, by chance, they come frequently to the attention of the research worker or administrator; when they catch, momentarily, the

fleeting attention of the capricious public eye; when examples of the problem exist close to the research headquarters. Sometimes problems that appear to be outstanding are truly so; but, in too many cases, they are outweighed in importance by other, less apparent ones.

As NEIL STEVENS (1945) has emphasized, field observations, surveys, are of critical importance in determining how a worthwhile research program shall be chosen. As we will see later, the value of these surveys in orienting research increases with increase of the definiteness of the survey data and of their interpretation in terms of crop loss and the economic consequences of this loss.

"Life is far too short to carry out experiments to decide whether a given disease is, or is not, worth studying," writes STEVENS. This is true if the researcher is alone in his efforts, but he need not be. There is a small but growing body of comparative data to which he may turn in his attempt to evaluate the importance of the problem at hand. With the combined efforts of many pathologists over a period of years, it may not be too visionary to suppose that there will gradually be evolved a picture of comparative agricultural hazards which will be of very material aid in selecting the most productive areas for research.

Even such inadequate comparative data as are now available may be of some limited help in selecting problems. An example of this, for facilitating research on new fungicides, has been given by McCALLAN (1946), who derived an "index of disease importance" to indicate the most pressing problems in fungicide research (p. 288). Approaches such as this will have greater and greater value in the planning of research as we develop a more reliable basis of knowledge on the extent and relative importance of the losses from the various diseases of crops.

DISEASE APPRAISAL AS A RESEARCH TOOL: -- Besides its value in initiating research, the determination of the distribution, intensity, and destructiveness of plant disease frequently may be an important element in the research itself. Studies on the ecology or epiphytology of disease, as STEVENS (1945) has pointed out, depend largely or almost entirely on estimates of disease losses determined by survey methods. The most precise and detailed laboratory, greenhouse, and field plot experiments on the survival and spread of disease and its relation to the environment, must be validated by analysis of disease development under natural conditions over a wide area. This analysis, if it is to be of value, must be made by methods of determining disease intensity and loss which are reasonably accurate and reliable. Excellent examples of the contribution which disease appraisal makes to research are found in the 8-year ecological study of fruit tree diseases in Illinois, made by TEHON and STOUT (1930). Using objective methods of scaling disease intensity, they arrived at numerous conclusions on the ecology of various fruit diseases through a study of the variation in disease intensity in different years, crops, and diseases of the same crop.

Standardized and reasonably accurate methods of measuring disease intensity and loss again are helpful or indispensable in disease control experiments. Whether attempted control is through the use of fungicides, the development of disease-resistant varieties, or some modification of cultural practices, in all cases, the experimenter must find a means of comparing and expressing, in quantitative terms, the differences in disease intensity between treated and check plantings. He needs, further, to correlate these differences in disease intensity with yield differences. To him, a standardized, objective, quantitative system of appraising disease intensity and loss is the yardstick by which he measures the progress of his research and by which he demonstrates to others the success of his accomplishments and their value in practical agriculture.

PLANNING EFFECTIVE TEACHING AND EXTENSION ACTIVITIES: -- As in research, so in educational work, -- the need is great, the workers are few, their efforts must be directed at the problems that are actually, not only apparently, of greatest importance. The extension plant pathologist selecting the limited number of projects that will constitute his program, the teacher of plant pathology, the writers of textbooks, bulletins, and popular accounts of plant diseases, those whose work is agricultural education in any manner, all have the same need of concentrating their limited efforts on those pathological problems of greatest real significance. The most useful direction of these efforts depends on a comparative knowledge of the losses caused by the various diseases, based on tested methods of disease appraisal, extended to cover significant areas by disease surveys, with the findings interpreted in terms of agricultural and general welfare.

In educational work, facts, not guesses, must support efforts to encourage laymen to follow and support plant disease control practices. These facts on the seriousness of diseases and the need for their prevention can only be obtained by systematic, scientific disease loss appraisal.

Examples of the value of plant disease surveys to the agricultural extension worker have been

given by CHUPP (1945) and the usefulness of sampling in extension work has been discussed by SABROSKY (1946). Mrs. SABROSKY'S paper deals with personal polls as an aid to extension work, but the principles apply equally well to samplings of crops. At several points in the extension worker's program, such samplings are helpful in determining the needs for extension activity and program planning; in ascertaining the extent to which recommended practices are being carried out and are proving effective; and in assembling data required for periodic reports.

DETERMINATION OF THE ECONOMICS AND VALUE OF PLANT DISEASE CONTROL MEASURES: -- The expense of disease control is justified only when it can be demonstrated that the cost of control is materially less than the loss suffered when the disease is uncontrolled. The cost of control can be easily calculated; the cost of disease, on the other hand, can be determined only by experiment, measurement of loss, and economic analysis of the loss factor. This is more difficult, yet it must be done before the expense of control practices can be recommended with assurance.

The comparison of these two costs, that of disease loss and that of disease control, must be made under the practical conditions of growing and handling crops. The efforts of both research scientist and extension or survey worker are required, the former to provide dependable methods of disease intensity and loss appraisal, the latter to use these methods under conditions of commercial crop production, storage, and marketing, on a sufficiently broad scale to assure that the economics in favor of control practices are generally applicable. The end result, to expand NEIL STEVENS' (1938) phrase, is the advice to the practical men of agriculture: "If your loss is less than X%, forget it. If it is as high as Y%, you will profit by spending Z dollars to prevent it." Y cannot be guessed at; it must be measured.

There are, doubtless, many cases of plant diseases against which no efforts at control have been directed because, although the loss is considerable, it has never been conclusively demonstrated. In such cases, we can expect that the measurement of loss may be followed by the economically sound, widespread use of more or less costly control measures. There are many crops which are never sprayed or dusted, on which the cost of fungicide applications might be a profitable investment. Important forage legumes are in this category. The measurement of losses caused by soil-borne root diseases may reasonably be expected to be followed by an important extension of the practice of soil disinfestation, once the cash value of this has been shown. Plant pathology may learn a lesson from recent findings in entomology, where, as pointed out by PEPPER (1947), "the remarkable yield increases from new insecticides indicate that it may be profitable to use insecticides on low income crops such as hay and pasture." He cites, as an example, a 50% increase in alfalfa yields from one application of an insecticide, indicating formerly unsuspected insect damage to this crop.

A knowledge of the amount of crop loss from a disease may be helpful, not only in determining whether or not to apply control measures, but also in deciding which of two control measures, one costly but highly efficient, the other less expensive and less efficacious, to use. The cost of the disease, if known, would determine, for example, whether to combat tomato leaf diseases by the partially efficient, inexpensive methods of sanitation, tillage, and crop rotation, or whether to resort to the more costly but more efficient use of fungicides.

In developing, through research, a new method of plant disease control, every plant pathologist has the hope that it will become widely used. He can stimulate its use if his announcement contains experimental data demonstrating that the cost of the control measure is substantially less than the loss which it prevents.

In the recurrent periods of fungicide scarcity, as in both world wars, it is a matter of national security that the limited supply of chemicals be applied against those diseases which would occasion the most serious losses if uncontrolled. Choice of the diseases to be controlled, under these conditions, depends on the value of the crop in the national economy, which is known, and the loss in that crop if certain diseases are uncontrolled, which must be measured. From this point of view, a reliable body of data on comparative crop losses from diseases is a national resource.

APPRAISAL OF THE PRESENT AND POTENTIAL SALES VALUE OF THE CROP: -- Foreshadowing what might be done in applying knowledge of crop losses to agricultural planning and action programs, we have, as a solitary but outstanding example of what has been done, the case of forest appraisal. In determining the value of timber in the forest now or at some specified future date, the appraisal of loss due to decay has become an exact science, and a needed one, because erroneous appraisals discourage contracts and sales.

By use of suitable techniques which have been developed, tested, and approved, it is possible for a well-trained timber cruiser to determine the amount and value of cull which must be

deducted from the apparent volume of timber in a forest, in order to calculate the net merchantable timber with sufficient accuracy to permit intelligent financial operations in marketing of the crop. Since decay is the leading cull factor and cause of timber loss, its accurate appraisal goes far in determining the value of the timber.

By means of correlations which have been established between present cull amount or present cull indices and the amount of cull at any specified future date, it has become possible to calculate, with a practically sufficient degree of accuracy, not only the present sales value of the crop, but its future sales value, and from this, to determine the increments of increasing or decreasing value of the forest investment in future years.

Detailed discussions of the appraisal of sales value of standing timber are commonly given in books on forest mensuration and forest pathology. Particularly recommended to those who wish to study further, this aspect of crop loss measurement is the chapter, "Loss and Appraisal of Damage", in D. V. BAXTER'S book, "Pathology in Forest Practice", (1943).

There appear to be few, if any, cases, other than that of forests, in which appraisal of loss from disease, present or potential, is commonly used in determination of the sales value of the crop, other than in a very general and inexact manner. The estimation of hail damage for crop insurance purposes is considered below in another connection. Yet, one can think of many instances in agriculture in which the development of proven methods for determining the influence of the disease factor might be extremely helpful in connection with the sale or rental of farm properties.

This would apply particularly to perennial herbaceous crops such as alfalfa, to nursery stock, to fruit and nut orchards, and to shade trees. In the cases of the tree crops, some of the methods of forest disease appraisal might be applied, with modifications, supplemented by others. As one of many possible examples, the value of alfalfa stands often depends largely on the rate at which they deteriorate from bacterial wilt (Corynebacterium insidiosum). The studies of SALMON (1930), GRABER and JONES (1935), and WEIHING, et al., (1938), on the annual tempo of wilt increase and forecasting wilt losses in future years, if supplemented by data correlating alfalfa stands and yields, would provide a basis for fairly accurately determining the sales or rental value of an alfalfa field, insofar as this leading variable is concerned.

THE VALUE OF DISEASE LOSS DATA TO AGRICULTURAL ECONOMICS: -- There are many contact points between the various activities in the field of agricultural economics and the subscience of plant disease loss determination. Two of these, crop insurance, and land utilization, are discussed separately in later sections.

An important service is rendered to agriculture by the periodic crop news and yield forecasts issued by agricultural economists. The value of this service depends entirely upon its timeliness and accuracy. Some of the factors which have important bearing on crop yields and prices are unpredictable, which increases the necessity for full, balanced consideration of those factors that do have predictable effects on yields. There are numerous cases where plant diseases, acting over a wide area, produce important downward revisions of yield estimates by harvest time. In many of these cases, there exists, or could be obtained, the necessary information to enable the crop reporter to correct his yield estimates well in advance of harvest time. For every degree of greater accuracy and for every deductible day in the earliness of the estimate, its value to growers and marketers increases. The crop reporter needs to know the relative yield-depressing effects of the different diseases, and for each important disease, whenever this information can be secured, he needs to know that a given intensity of disease at a given stage in crop development is regularly followed by a given percentage reduction in crop yield at harvest time. Such information is already available for a few diseases, such as the smuts and rusts of wheat. If this could be extended to include the majority of important diseases of leading crops, properly supported by plant disease surveys to determine the acreages involved in disease, plant pathology could aid agricultural economics to strengthen materially its reporting and forecasting service.

Other points of contact between the two services occur in the compilation and analysis of production statistics and crop prices. Knowing the effect of given intensities of disease on yields and having available survey data of past years on disease intensity, it becomes possible to interpret the role of plant disease in the production totals, to determine the extent to which new disease-control measures may influence future production, and to gain some conception of the levels of production that are attainable with increased disease control. Since the damage from many plant diseases takes the form of lowering the quality of produce, this is reflected in the price received per unit of the crop. The analysis of price variations in the past would be materially aided by recognition of the extent, in any given case, to which disease loss is

expressed as quality reduction. Even the forecasts of prices to be received for crops not yet harvested will frequently be improved by definite knowledge of the effect of a given disease situation on the quality of the crop to be harvested later. In a year of destructive rust, a large amount of wheat with low test weight can be expected, and in a potato late blight year, a high percentage of storage and market spoilage can be predicted, but these are more or less isolated cases. We need reliable data that tell us under what circumstances and to what extent, quality reduction from disease, such as to affect price levels, may be anticipated.

Much that has been said above, in reference to disease loss appraisal as it pertains to sales value of the crop, may be applied to the related problems of farm taxation and farm mortgaging and credit. Equitable taxation rates and financially sound farm mortgages and loans depend on a knowledge of many factors, among which the chief one is the value of crops which the farm can produce, Since plant disease is one of the major variables in farm crop production, the disease factor is an important element in the productive capacity of the farm. The same applies to other growing stock, as nurseries or shade trees, which are taxable or which have value for securing loans.

Appraisal of farm lands for tax assessment purposes should be based on the productive capacity of the land. If the yields of the land fall short of its ability to produce because of crop losses due to negligence of the farmer to follow well-established disease control practices, the farm is none the less capable of producing higher yields and its taxation should be on that basis. The differential between apparent value, as seen in actual yields, and real value can be known, insofar as potential yields are reduced by preventable disease, only if one knows the extent to which given diseases reduce yields. Here, crop disease loss information, coupled with appraisal of the disease situation on given farms in question, gives a needed basis for assessment of farm taxes. A similar situation obtains with respect to farm mortgages and credits. The losses suffered from disease affect the loan value of the farm as truly as losses from soil erosion, and a reasonably exact knowledge of these losses is fundamental to evaluation of the farm for assuring security of farm loans.

In the economics of agricultural marketing, there is also an unsatisfied need for more accurate information on the extent to which plant diseases produce deterioration of harvested crops. The absolute amount of market wastage is enormous and is commonly regarded by the marketer as necessary "shrinkage". Most of this loss is caused by diseases, which in many cases are preventable. If we had a comprehensive and reasonably accurate basis of data for evaluating market losses in their true light, it would become recognized that such losses are not inevitable, efforts at their prevention would be justified and facilitated, and market loss prevention would no longer be largely a matter of trial and error. The results would greatly benefit both marketer and consumer, and the agricultural economist who deals with marketing problems would be provided with a more rational, scientific basis for his evaluation and interpretation of market losses.

Finally, a reasonably complete and accurate picture of plant disease losses could make an important contribution to the planning of national agricultural economy, particularly in time of war, when such knowledge becomes a factor in national security. An understanding of the amount of loss of strategic agricultural products caused by plant diseases, present or potential, would make it possible to anticipate such losses and maintain production to meet necessary quotas by increased efforts at disease control or by the planting of additional acres to offset the losses.

A case in point is that of the new Victoria blight of oats (Helminthosporium victoriae). Discovered in Iowa in 1945, in 1946 it destroyed one-fourth of the great Iowa oats crop. In Kansas, it caused 1% loss in 1946 when it was discovered, and a loss of 20-30% in eastern Kansas in 1947. It is now widespread throughout the United States, and many farmers have been discouraged from planting oats or have shifted from the rust- and smut-resistant but blight-susceptible Victoria types of oats to blight-resistant but rust- and smut-susceptible older oat varieties, avoiding one risk by assuming another.

A disease of this magnitude has a profound effect on national production, the full degree of which we probably have not yet witnessed. It unquestionably was a major factor in the meat famine of 1945. It exemplifies strikingly the need for agricultural economists to be supplied, at the earliest possible opportunity, with reliable information on the extent of crop disease hazards, so that such losses as these, telling blows to the national economy, can be diminished by agricultural planning for offsetting the losses by increasing the planting of substitute crops, or by more extensive use of disease control practices.

One can conceive of cases of the opposite sort. If a crop is already being produced in sufficient abundance, despite regular losses from disease, and if new, efficient disease control measures that will greatly reduce these losses are in the process of widespread adoption, economic dislocations from overproduction could be avoided by planning a reduced acreage to compen-

sate for increased acre yields, but this could only be intelligently done if the amount of loss suffered, and about to be prevented, is known.

To the plant pathologist, there appears to be an appalling lack of consideration of the destructiveness of plant diseases in the activities of agricultural economics. Cotton pathologists feel confident, for example, that diseases regularly destroy about one-fifth of the cotton crop. They are shocked to find, in official estimates of factors which reduce the cotton crop (e.g., Anon., Bur. Agr. Econ., U. S. Dept. Agr., 1944), that all cotton diseases are included in "all other" factors which combined are estimated to have an almost inconsequential effect in reducing cotton production as compared with insects and climatic factors.

It is true that the agricultural economist might make better use of what scattered information there is available on the amounts of plant disease losses, -- if he could find this information and could translate it into terms and on a scale similar to those in which other loss factors are expressed. But, so long as a reasonably complete and accurate body of information on plant disease losses is lacking, it is the plant pathologist and not the economist who must bear the brunt of the responsibility. Many ways in which economists could profit by this information have been suggested. Here is an undeveloped service to agriculture of great potential value. It rests with plant pathologists whether they will make the necessary effort to furnish the economist with the needed information on the amounts and kinds of loss caused by plant diseases.

THE VALUE OF PLANT DISEASE LOSS DATA TO COMMERCIAL AGRICULTURAL INTERESTS: -- Timely and accurate knowledge of crop losses is essential in making economical and profitable disposition of harvested crops. It has importance in such regards as allocation of suitable numbers of railroad cars or trucks to harvest points, the planning of canning and packing operations, management of crop storages to provide against shortages of supply, and determining financially sound price levels and commodity trading. Agricultural trade publications regularly publish news of crop disease outbreaks as a service to their industry. In these some attempt is made to weigh the effect of the disease on supply and marketing, but such attempts, at present, can be little more than speculation, in view of the lack of organized quantitative information on crop disease as a factor in reducing crop supply and quality.

Manufacturers and dealers in agricultural chemicals and equipment also have a stake in disease loss measurement. Such measurements may disclose new markets for their products. When it can be shown that a given disease causes a regular loss of a given amount, the manufacturer of fungicides, knowing the extent to which his chemicals can control the disease, is in a position to determine whether or not to undertake an extensive publicity and sales program. To him, the two most important points to be established are: (a) will his product control the disease; and (b) can the product be marketed at a price substantially below the benefit to be realized? The benefit, the crux of the matter, is that fraction of a healthy crop which may be destroyed by uncontrolled disease, the loss, and there can be no intelligent appraisal of the future markets for pesticides until the loss factor has been measured.

An example: Is there a market for fungicides to prevent defoliation in the huge national acreage of alfalfa? There is every reason to believe that available fungicides can control the leaf-dropping which is so common in this crop that one normally finds the ground about alfalfa plants carpeted with fallen leaves, the victims of fungus infection. As much as 50% of the foliage is commonly defoliated, lost from the hay and unavailable for aid to the plant in seed production. Are these leaves dropped after their usefulness to the plant is past or is photosynthesis somewhat or severely curtailed by their loss? In a word, what economic loss results from the defoliation? Is this loss sufficiently great to more than offset the cost of one, two, or more applications of fungicides? The loss has never been measured, evaluated, related to the cost of controlling defoliation. Yet, a major branch of the fungicide industry might develop on the basis of such measurements and analyses for alfalfa and a number of other field legumes.

Almost isolated in this field is the attempt by McCALLAN (1946) to find indications of the needs for fungicides by means of his index of disease importance, described on page 288. The attempt is praiseworthy. Its weakness, as McCALLAN recognized, lies in the imperfections of his initial data, the Plant Disease Reporter crop disease loss estimates. If plant pathologists could substitute measurements for the estimates, often little better than guesses, which these data represent, a very practical and profitable service would be rendered to commercial agricultural interests, one which they, to some degree, could underwrite with profit.

THE DETERMINATION OF HARVESTING CYCLES: -- In planning for the most profitable forest management, a comparison of timber growth increments and decay increments makes it possible to determine the most economical cutting cycle for each forest type. This use of plant disease loss measurement, which is exemplified in the pioneering work of MEINECKE (1929) on

quaking aspen and has since been extensively studied, makes it possible to avoid losses by harvesting the timber just before the inroads of decay begin to reduce the net annual increase of wood volume to an unprofitable level. The methods of measuring gross and decay increments will be considered in another connection; here, it is only necessary to point this out as another valuable contribution made through a fairly exact knowledge of the amount and nature of loss caused by plant disease.

In general, this principle does not apply to other crops than forest trees, but there may be an occasional exceptional case. For example, in hay crops that are harvested more than once during the growing season, the maximum tonnage that can be obtained will be the difference between gross growth and the amount of growth which is lost through various causes, particularly leaf and stem diseases. The approach to this problem might parallel that in the forest. Increments of growth and of tissue loss could be measured, and from these measurements, it should be possible to determine both the most profitable intervals between mowing and the increase in hay expected to follow the development and use of direct disease control measures.

THE DETERMINATION OF THE PROBABLE SUCCESS OR FAILURE OF NEW AGRICULTURAL VENTURES: -- "The vindication of the obvious is sometimes more important than the elucidation of the obscure," wrote Chief Justice HOLMES. It is obvious that any new agricultural venture should be preceded by a careful analysis of the hazards involved; it is equally obvious that plant disease can frequently be a principal hazard in attempts at introducing crops into new areas. Yet, the list of agricultural failures due to neglect of this obvious hazard is a long and costly one. STEVENS (1934b) has listed more than 50 cases of agricultural projects that failed because of unforeseen or disregarded plant disease, a sad record of high hopes followed by disaster, crop abandonment, and farm failures.

In most such cases, the hazard could have been foreseen had there been appreciation of the destructiveness of the diseases in question and knowledge of their occurrence in the areas of the proposed projects. The trial- and -error method is a costly one, yet, in most cases, it has been the only means by which planners and growers have been dissuaded from their pathologically dangerous undertakings. In isolated cases, disease loss determinations, disease surveys, and disease hazard maps have made it possible to avoid certain disaster. One of these is the praiseworthy mapping of the Texas root rot (Phymatotrichum omnivorum) danger spots in Texas and Southwestern Oklahoma by the Division of Forest Pathology, U. S. Dept. of Agriculture, in cooperation with the Prairie States Forestry Project. The purpose was to delimit and define the disease hazard so that shelterbelts and nurseries of susceptible species could be located safely, while resistant species could be planted in infested soil.

An adequate basis for predicting the influence of pathology on contemplated agricultural ventures comprises several steps: measurement of the damage which diseases, at given intensities, are capable of producing; determination of past extensions of disease areas and of their present areas by survey methods; study of the ecology of diseases to determine the likelihood that a given disease could prosper in a new location and environment; and a summarizing of this information in the form of disease hazard maps to be used in agricultural planning, in the same manner and with the same advantages as land use maps or soil survey maps.

Part of the information needed for the construction of disease hazard maps is available. Disease loss measurement and disease surveying, two essentials, are treated throughout this book. Information on the ecology of plant diseases is commonly included in publications dealing comprehensively with the diseases. In many cases this information should be supplemented by trial plantings of the crop in the proposed new areas, preliminary to large-scale production undertakings. In the last essential, the summarizing of this information in the form of plant disease hazard maps, the data now in hand have not been fully utilized.

The geographic distributions of numerous plant diseases has been mapped, for example, in many instances in the volumes of the Plant Disease Reporter. The most extensive effort of this sort has been by the Imperial Mycological Institute at Kew, it series of "Distribution Maps of Plant Diseases" now including more than 100 maps. Because of their small proportions, their use as hazard maps is limited to crop planning on a major geographic scale. Yet, they are very helpful in showing at a glance the restricted areas of such crop-limiting diseases as Texas root rot, sugar beet curly top, peach yellows, and cotton leaf curl; the world-wide distribution of others such as the Fusarium wilts of banana, flax,, and crucifers, citrus psorosis, and flax rust; and the scattered but non-uniform distribution of still other destructive diseases, including onion yellow dwarf, tobacco downy mildew, and the Dutch elm disease.

Each map of this kind shows only the present distribution of one disease of a single crop. It has some use in agricultural planning, but there would be much greater aid if the needed data could be assembled in the form of maps, each showing the distributions of all major diseases of

a given crop and, insofar as possible, the present non-infested areas in which these diseases are ecologically adopted and might be expected to flourish, if introduced. WEIR (1918) has called attention to the frequent use of pathological forestry maps in Germany, although they have not become commonly used in the United States, and NEIL STEVENS (1938) has mentioned having partial material for plant hazard maps; on two occasions, he attempted to interest the American Phytopathological Society in the development of such maps, but without success.

THE DETERMINATION OF THE LIMITS OF SAFE EXCHANGE OF AGRICULTURAL PRODUCTS AND OF DISEASE-REGULATORY ACTIVITIES: -- In many cases, the danger of introducing plant disease into a new area is so great that prudence demands prohibition or regulation of the movement of propagation materials or other crop products. Embargoes may have economic disadvantages and regulation is costly; these measures should therefore be based on a sound understanding of the potential destructiveness of the disease if it is introduced into a new area.

As with other disease-control measures, the necessity for and value of control by embargo or regulation are functions of the amount of loss the disease is capable of producing. The threshold loss amount, above which, regulation is justified and below which, the cost of regulation would not be warranted, should be the deciding factor in weighing the desirability of regulatory measures.

The threshold loss amount is a complex factor involving all economically important diseases of a given crop that might be introduced through commodity shipments and their combined potentiality for reducing yields in the new environment of the import territory. Despite its complexity, it would appear possible to determine the threshold loss amount with a sufficient degree of accuracy to serve the useful purpose of guiding the practice of disease control by regulation.

Several steps are involved: surveys to determine the incidence of diseases in the export region; measurements of the amounts of loss that they cause; testing, in the export region, of crop varieties that are grown in the import area to determine the degree to which they are subject to losses from the disease factors; determining the extent to which the diseases in question may survive transport and be able to establish themselves in the new area; and analysis of climatic and other environmental factors in export and import areas to ascertain their probable effects on establishment, persistence, and severity of the diseases in the new area. What has been said in the preceding section regarding disease hazard maps applies equally here; such maps are a good and needed means of summarizing the disease danger for the purposes of regulation.

Here, we are primarily concerned with one of these steps, the measurement of disease losses, in some respects, the least studied but most essential step of all. Suppose that a disease is transported, established, persistent, it still has little significance for the regulatory worker unless its capacity for causing crop loss can be demonstrated to be sufficiently great to outweigh the cost and economic dislocations of regulatory measures. Here, on an international scale, we again recall NEIL STEVENS' advice: "If your loss is less than X%, forget it!"; and again, we must know the value of X.

Some attention has been given to this problem in connection with seed-borne diseases, particularly, tuber-borne virus diseases of potatoes. In Bermuda, WORTLEY found by experiment that potato mosaic caused a loss of 50% and that the disease was introduced into Bermuda in imported seed stocks. As a result of his investigations, the importation of potato seed tubers was wisely brought under regulation. At the request of the Certification Committee of the Potato Association of America, LECLERG and others (1944, 1946) conducted tests in seven States during several years to determine the maximum percentage of virus-infected tubers that can be tolerated in seed potatoes without expectation of significant yield reduction. Their tests showed that the threshold value for loss was about 4% leafroll or spindle tuber; less than this amount of seed contamination did not constitute a serious meance to the grower; and this threshold value, once determined, could then be used to establish economical and safe certification standards.

What has been done in these two isolated cases can and should be done for many other diseases that are considered for regulation. Only with this type of information, can regulation be devised in such a way as to afford sufficient protection at the least cost in regulatory expense and economic hardship.

PLANNING BY FARMER-ASSISTANCE AGENCIES: -- A number of Federal agencies have been created for the purpose of assisting farmers in one way or another. The relation of plant disease losses to the work of certain of these, such as the Agricultural Extension Service and the Federal Crop Insurance Corporation, is discussed in other sections of this chapter. Here, we can consider plant disease losses in connection with the services of the Soil Conservation

Service, the Farm Security Administration, the Agricultural Adjustment Administration, the Commodity Credit Corporation, the Farm Credit Administration, and the agency which coordinates the work of some of these and other farmer-assistance organizations, the Office of Land Use Coordination.

All of these agencies are concerned with ameliorating and safeguarding the welfare of farmers, which depend chiefly on improving conditions of production and marketing of farm produce. Since plant disease is a major hazard in both crop production and marketing, it is to the interest of each of these agencies to know the extent of this hazard and give it due consideration in their action programs. When public money is spent to assist farmers in producing and marketing crops, and when these growing or harvested crops are destroyed by disease, the public money is wasted. This is excusable if the loss was inevitable despite careful planning; it is unpardonable if the loss was the result of negligence on the part of administrators who have failed to give attention to pathological hazards. Recklessness on the part of a driver who speeds his vehicle across hidden intersections may have its counterpart in reckless spending when foreseeable hazards are disregarded. Insofar as plant pathologists have failed to furnish such agencies with reliable data on the plant disease loss hazard, they must share the responsibility for this waste of public resources.

A major impediment to securing and using disease loss information in relation to farmer assistance agencies is the policy of "avoiding entangling alliances" which often isolates these agencies, despite their common interest in the welfare of the farmer, and which, in particular, prevents an advisory relationship with exchange of crop loss information between the action agencies and plant pathologists. The staffs of these Federal agencies are deplorably deficient in lacking the services of plant disease specialists, and their policies of isolation prevent their securing the aid of plant pathologists in other Federal or State agencies, despite the willingness of the latter to cooperate.

Among many examples, there is the case of a farmer who was resettled on a rich bottom-land farm in southern Oklahoma. In the course of time, he was offered assistance to purchase the farm. Meanwhile, his cotton had been seriously damaged by Texas root rot. He refused to buy or remain on the farm because he knew the destructiveness of this disease and was inexperienced in growing root-rot-resistant substitute crops. The money spent in the attempt to resettle this farmer was wasted, although the invariable destructiveness of root rot in cotton is well known, and the occurrence of root rot on the farm (which would have been suspected from the location of the farm) could have been very easily determined.

After the costly experience of trial and error, some agencies have begun to include the disease hazard in their planning, in a limited way. The Soil Conservation Service issued orders that its nurseries be located outside the known root rot area and in locations not infested with root knot nematodes. The Forest Service approved only disease-resistant species for shelterbelts in the areas which it found by surveying to be infested with root rot. Soil Conservation County Committees in root rot areas have begun to recognize root rot infestation as a factor ranking with soil fertility and moisture supply in determining the type of local farming that will succeed.

Important though the disease hazard may be in long-established types of farming, it assumes even greater importance with changes in type of farming such as are frequent today. Introduction of irrigation, shifts in cropping practices, the culture of new types of crops, intensification and mechanization of farming, all may produce changes, some of them of critical importance, in the disease hazard. Plainly, we are faced with a twofold obligation: on the part of plant pathology, to furnish action agencies with as complete and reliable a body of information on the occurrence and destructiveness of plant diseases as is possible; and, on the part of the action agencies themselves, to make full use of this information in assisting in farm planning, advancing credit, marketing aid, and the other services for which these agencies are responsible.

THE BASIS FOR CROP INSURANCE AGAINST DISEASE LOSSES: -- Few professions are subject to such unpredictable and uncontrollable losses as that of farming. Insurance to protect the farmer against disastrous crop losses would appear to be one of the most valuable means for stabilizing agricultural income and improving the lot of the farmer. However, crop insurance is a most complex and difficult type of insurance to write on a sound financial basis for a number of reasons, including the variety and unpredictability of the risks, instability of the value of the insured property, and difficulty in appraising the amount and character of losses.

Because of these difficulties, many attempts at crop insurance, made by private insurance companies in the past 50 years, have all failed (Report of the Manager, Federal Crop Insurance Corporation, 1947). Since farmers did not have this aid from private enterprise, Congress passed the Federal Crop Insurance Act of 1938. Wheat was first insured in 1939, cotton in 1942,

tobacco, corn, and flax in 1945, and the Act provided for experimental insurance of other crops. In 1947, after insurance of wheat, tobacco, and corn had resulted in credit balances, with a slight loss in flax and substantial losses in cotton, the entire program was placed on an experimental basis, since it was recognized that development of a sound crop insurance program is a long-time project, requiring many years of accumulated experience.

The Federal Crop Insurance program aims at protecting farmers from production risks over which they have no control, from seeding to harvest and threshing time. Indemnities for crop losses are paid on a basis of "average normal yield" for the insured farm or comparable farms in the area. They do not cover "avoidable losses such as those resulting from the use of defective or unadapted seed, failure to properly care for and harvest the crop, or failure to follow established good farming practices" (correspondence, F.C.I.C., 1947). These omissions are interpreted to include failure to prevent losses from plant diseases that might have been avoided by standard disease control practices such as the use of disease-free or disinfected seed, disease-resistant varieties, spraying or dusting, and other "reasonable and practicable disease control measures".

In practice most crop insurance indemnities are for losses caused by climatic factors such as droughts, floods, frost, or "poor growing conditions". At times, there have been substantial indemnities for insect damage, particularly from the cotton boll weevil and the corn borer. Indemnification for losses due to crop diseases are extremely low, entirely out of proportion to the damage caused by disease. In the case of wheat, for example, it has been authoritatively established that of all causes of crop loss, 80% are due to weather and miscellaneous factors, 12% to diseases, and 8% to insects. This figure for diseases, 12% of all losses, compares with actual indemnities for wheat diseases paid by the F.C.I.C. in 1940, 1941, 1942, and 1945, respectively, of 3.1%, 5.9%, 1.1%, and 0.76% of all indemnities paid on this crop. Diseases of wheat and estimation of the losses caused by them have been more thoroughly studied than is the case with cotton and other crops, where the disparity between the figures for indemnified disease losses and those for all losses in the crop is even greater. For 1945, the indemnities for all diseases in cotton, corn, and flax, in each case, were less than 1% of indemnities for all causes.

There are several reasons for the disproportionably low indemnities for disease losses. Some disease losses are preventable and therefore non-insurable. Others are not recognized as diseases by insurance adjusters and are classified under such captions as "excess moisture". Insurance covers only 50 to 75% of the average yield and disease losses of less than 50 or 25% of the average yield, in the two cases, might be disregarded or subordinated to more spectacular climatic loss causes.

But there is another, very important reason why plant disease losses have been given such trifling consideration in crop insurance, the fact that there is no comprehensive and useable body of information on the amount of damage caused by plant disease. Without this information, there is no sound basis for determining indemnities, therefore, plant diseases are almost disregarded as insurable loss factors.

The development of an objective basis for hail insurance illustrates what can be done and what needs to be done for crop diseases. With corn, (DUNGAN, ELDREDGE, KIESSELBACH and LYNESS), small grains (ELDREDGE), onions (HAWTHORN), flax (KLAGES), and soybeans (ELDREDGE and KALTON), in each case, experiments in which the crop was injured in imitation of hail injury have shown the amount of loss sustained by hail injury of different degrees of severity and at different growth stages. These experiments have provided a sound basis for hail insurance, the only type of crop insurance which has been scientifically based and the only one which is a proven success.

What has been done in providing a sound basis for successful hail insurance can and should be done for crop disease insurance. This need not be done for all diseases, but only for those that are significantly destructive and beyond the control of farmers. Since some diseases are highly destructive only in occasional or rare years, this type of insurance would need to be on an experimental basis for a sufficiently long time to permit calculation of reliable average losses. Attention must be given to the distinction between locally important diseases (which do not seriously affect average loss percentages, but which require more intensive appraisal) and diseases that occur more or less uniformly over wide territories. Because of the pathological characteristics of this risk, the development of successful crop disease insurance will require intimate collaboration of plant pathologists and crop insurance personnel.

Extended accounts of crop insurance are contained in the annual reports of the Federal Crop Insurance Corporation since 1943, and the papers of VALGREN (1922) and SCHLUMBERGER (1927).

THE VALUE OF DISEASE LOSS DATA IN OBTAINING SUPPORT FOR PHYTOPATHOLOGICAL RESEARCH, EDUCATIONAL, AND REGULATORY WORK: -- Last among the applications of information on crop losses from plant disease, but ranking high in importance to plant pathology, is the usefulness or indispensability of this information for securing financial support of pathological work. LYMAN pointed this out in 1918 (see quotation in Prologue), but, for the most part, his counsel was unheeded, and almost 30 years later, PAUL MILLER (1946) was impelled to remind pathologists that "if crop loss estimates are used to the extent of determining appropriation of public funds, we should either meet the challenge and improve their quality, thus putting ourselves in a position to defend their validity, or else admit their shortcomings."

Everyone who has dealt with administrators of funds will agree that the demonstration of the dollar and cents value of a proposed undertaking is the most persuasive of arguments. We know that plant diseases often cause enormous losses, that our modest requests for financial support represent but trifling fractions of those losses, and that our accomplishments in plant disease control repay manyfold the cost of our work. But, our own sincere convictions, unsupported by evidence, cannot be expected to persuade hardheaded men of finance of the value of our proposals.

Lately, there have been a few instances in which it has been possible to express the value of research in the concrete terms with which these men are familiar. REITZ (1947), in promoting an expansion of hard red winter wheat research, has demonstrated that a research investment of $200,000 per year has resulted in the production of 8 new wheat varieties which outyield the older varieties, because of disease resistance and other qualities, by 10 to 30%. These have produced a benefit of $50,000,000 per year or $250 of new wealth for every dollar invested in research. Similarly, CRAIGIE (1944) has shown that the introduction of rust-resistant wheat varieties in the Prairie Provinces of Canada has resulted in an annual yield increase of 41,339,000 bushels valued at $27,242,000. The research which produced these varieties cost a total of $2,000,000. The profit *in each single year* is 13 times the total cost *in all the years* of the research that produced the new varieties.

The U. S. Department of Agriculture, keenly aware of the necessity of demonstrating the profits of research in competing for appropriations, has encouraged its personnel and their collaborators to supply data on the cost and profits of research, and the "Research Achievement Sheets" published from time to time by the Department contain reference data which include the cost and the value of each discovery.

The prosperity of plant pathology as a science depends most on the financial support which it receives. This support, in turn, depends to a major extent on the ability of plant pathologists to demonstrate the economic value of their work. The latter, finally, depends on the accumulation of reliable data showing in reasonably accurate terms the amounts of loss caused by the various diseases and, consequently, the gain from disease control that has been attained or is in prospect. From this point of view, the securing of these data, the measurement of plant disease losses on a broad and comprehensive scale, is not just another optional facet of pathological studies; it is vital to the prosperous future of the science.

THE ECONOMIC VALUE OF PLANT DISEASE FORECASTS: -- "Famine conditions in Europe and Asia have been aggravated sorely by a disastrous crop failure in the southern hemisphere. Not until December came, could the world's planners possibly know that the trans-equatorial fields had failed to yield their expected harvests, and by then, it was extremely late for the planners to design a new program of famine prevention."

This editorial from *The Daily Oklahoman*, April 29, 1946, strikingly illustrates the important service that can be rendered agriculture and society by developing the ability to forecast crop prospects reliably and predict crop losses or the escape of crops from loss factors. The crop hazards that vary from one season to another, the uncertain factors for which forecasts might be most useful, are weather, insect pests, and crop diseases. The situation with regard to each of these factors may be favorable, harmful, or ruinous. Progress toward the more accurate and more timely forecasting of losses or escape from any and all of these factors is progress toward sounder agricultural economy whether viewed from the standpoint of the farmer, individually or collectively, the handlers of agricultural commodities, or the national economy.

To the farmer, a reliable crop disease forecast appears to be most useful if it enables him to avert predicted disease outbreaks by timely intervention of disease control measures, such as crop spraying or dusting, or to save the expense of these control measures in those seasons in which the forecasts are for relative freedom from disease. This value of timely warnings has been repeatedly demonstrated in the forecasting and spray-warning services for preventing losses from the downy mildews of potatoes and grapes. The former were initiated in Italy in 1922, and the latter in Holland in 1926. These services soon became widely used in Europe and were the forerunners of the American potato and tomato late blight forecasts, evolved during

World War II, and since made the basis of a formal, nationwide plant disease forecasting system. (cf. pages 328 ff.). Blight forecasts and spray warnings have been issued in sufficient time to avert blight losses by spraying, and in years of minor blight, as in 1947, potato and tomato growers have been saved the considerable expense of unnecessary spraying.

Plant disease forecasting falls within the field of this discussion of plant disease appraisal from two points of view: first, because forecasting depends on the determination of disease intensity and its change in relation to weather, so that the reliability of forecasting depends on the accuracy of disease intensity appraisal; and, second, because the value of a plant disease forecast becomes greatly enhanced if the amount of loss that may be expected, and not merely intensity of disease outbreak, can be predicted. A disease forecast in terms of probable loss, for example, not only tells the potato grower that this is a season in which spraying will be warranted, but may also give him a basis for deciding how much spray expense is likely to be offset by the difference in yield between sprayed and unsprayed fields. Each advance toward more uniform appraisal of disease intensity, and toward correlation of a given disease intensity with the consequent loss factor, will thus contribute toward more reliable and useful forecasting.

Plant disease forecasts may also be useful to the farmer and others even though the nature of the crop and disease are such that direct control measures cannot be applied. As an example, there is the case of the southwestern winter wheat grower whose stand of wheat is only fair, because of drought at planting time or winter injury. He is undecided whether to permit the crop to continue growth to maturity or to pasture it off or cut it for hay and plant the land with a substitute summer crop of corn, sorghum, field legumes, or cotton. His neighbor is undecided whether this is likely to be a season of abundant yields justifying him in purchase of a combine for custom harvesting. Another neighbor is undecided whether this year the crop will justify the expense of constructing additional crop storage facilities, and the local grain elevator operator has similar problems. The local railroad agricultural agent is undecided as to the extent of provision to be made for disposal of the crop, and the banker would like to know how much credit he can allow on the security of the coming harvest.

To all these men, reliable forecasts of crop yields or yield factors are valuable aids, contributing toward a sounder agricultural economy. Plant disease is only one of the several yield factors. In itself it does not necessarily spell crop success or failure, even though its effects are commonly late in the growing season of the crop, when most other yield hazards lie behind. It would be folly to attempt to predict yields from a knowledge of this factor alone. Yet, it is a weighty factor. Plant disease forecasts in conjunction with long range weather and insect pest forecasts can be of great service to agriculture and the industries dependent on agriculture, and in whatever measure even one of these hazards can be forecast, to that extent a partial service is rendered.

Plant pathologists are unduly timid about disease forecasting, as though a single erroneous forecast would be ruinous to their reputation. The official weather forecasts have an accuracy of about 80%, yet no one questions their utility. A comparable margin of error is acknowledged in the "predictions of things to come" by leading news commentators, agricultural and industrial publications, economists, and those who conduct public opinion polls. Yet, these predictions are eagerly received and often put to good use. No one expects the forecaster of weather, news, prices, or plant diseases to be infallible; if his forecasts are correct four times out of five, they are of proven value and far preferable to no forecasts at all.

The latent plant disease forecaster may be inhibited for other reasons than fear of the consequences of an occasional error. Many plant pathologists who are in positions to forecast plant disease are in tax-supported organizations, and they may be restrained from forecasting lest it direct the taxpayer's attention to the temptation for public officials to take private advantage of their foreknowledge of crop prospects. In other cases, they may be deterred from making low-hazard forecasts by fear of criticism from poorly-informed agriculturists, who regard such forecasts as harmful because of their possible effect in reducing farm crop prices. But these objections to forecasting are economically unsound; they avoid a lesser, real or imaginary evil by accomplishing a greater one, -- depriving the men of the agricultural industry of information that would contribute toward more profitable and economic production and marketing.

While crop disease forecasts are of value to the farmer, the processor, the marketer, the manufacturer and distributor of fungicides, and all of the others who are concerned directly or indirectly with harvest returns, from a national point of view, such forecasts assume even greater importance. The economies of this nation and of those other nations that must depend on this one for agricultural produce, are dependent on our production levels. If these levels are threatened by disease or any other hazard, the sooner this can be foreseen the greater the opportunity will be for averting the losses by crop protection or compensating for them by substitute production practices or conservation measures. In this light, the forecasting of crop hazards, specifically, the forecasting of crop disease outbreaks and losses, is a national resource.

Chapter II

THE DEFECTS IN PRESENT PLANT DISEASE APPRAISAL PRACTICES

Plant disease surveys have never been highly organized and strongly supported, with the result that existing data on plant disease occurrences, intensities, and resultant losses are incomplete and non-representative. Lacking standard methods for scaling disease intensity and with little experimental basis for determining the losses caused by plant diseases, our estimates of these losses, in the few cases where we have them, are often in error, as has been seen when estimates have been compared with measurements. These defects in our knowledge of plant disease losses, and the reasons for them, are discussed in the present chapter.

THE FRAGMENTARY AND ILL-ASSORTED CHARACTER OF SURVEY AND LOSS DATA: -- No other country has made an attempt comparable to that of the United States to assemble extensive data on the distribution in time and space, intensity, and destructiveness of all principal diseases of crops (MORSTATT, 1937). In the United States the most extensive repository of these data is the mimeographed publication of the U. S. Department of Agriculture, the Plant Disease Reporter, the volumes and supplements of which have been regularly issued since 1917. We can regard the Plant Disease Reporter as the best source of disease prevalence and loss data now available.

The Plant Disease Reporter is an extremely valuable reference work. From it the plant pathologist may glean a wealth of data that are helpful in studies of disease occurrences, in space and time, and of the ecology of plant diseases. The shortcomings of these data, from our standpoint, are largely due to the incompleteness and non-uniformity of the reports, which are submitted voluntarily with such varying degrees of completeness, accuracy, and uniformity as may be possible or appear essential to the contributors. There is a tendency to report only extreme cases of disease outbreaks from which destructiveness averages cannot be derived. Many of the reports are of disease occurrence only, without information on its severity. Many others indicate severity by such general terms as "worse than usual", "very injurious", and "unusually prevalent" which convey little meaning to the reader who is unfamiliar with the average situation in the area concerned, and none to the analyst who is attempting to place disease severity on a numerical basis. In some of the reports an attempt is made to define disease severity by reference to a standard scale, such as the COBB rust scale (see page 244), but for a given disease the scales may differ in kind and accuracy, and in the majority of reports, if disease intensity is mentioned it is in terms of a verbal scale which may be understood only by the contributor himself.

It is often impossible to determine from the reports whether disease outbreaks are general over a wide area or localized on a few farms. The data from some agricultural areas are much less complete than those from other areas which are better staffed. Due to the personal research interests of individual reporters, the spectacular character of some diseases contrasted with the more subtle destructiveness of others, and other factors, we find some crops and diseases much better documented than others.

The strength of the Plant Disease Reporter is in its records of disease occurrences. Its data on disease intensities, for comparative purposes, are weaker for the reasons cited. The volumes contain many references to single instances of disease losses which are useful as examples of loss and to some extent roughly depict the relative injuriousness of the various diseases, but because of their incompleteness and lack of uniformity they have only limited value in attempting to gain a reliable comparative view of the destructiveness of the various diseases in one or several crops.

Annual crop loss estimates, issued as Supplements to the Plant Disease Reporter, from 1917 to 1939 and then discontinued, tabulate the losses caused by a few leading diseases and by "all diseases" in each of several major crops. These are compiled from the estimates of key pathologists in each State and vary from highly accurate appraisals, based on extensive surveys and a knowledge of disease intensity-loss relationships, to others, perhaps a majority, which are little better than guesses.

There is no other body of data on plant disease prevalence and losses comparable to the files of the Plant Disease Reporter. Isolated useful data are scattered through thousands of other books, periodicals, bulletins, and special survey reports, and are found summarized only in very infrequent cases, in the few papers devoted to studies of crop loss from disease. In general, the limitations of the Plant Disease Reporter data, from our point of view, are equalled or exceeded by the weaknesses of these other scattered references to disease intensity and loss.

THE VALUE OF RELIABLE ESTIMATES, VERSUS MEASUREMENTS: -- One sometimes hears criticisms of estimates as though they had no place in the activities of accuracy-loving scientists. As authoritatively defined, "an estimate is a judgment or opinion, usually implying careful consideration or research; a judgment made by calculation, especially from incomplete data; a rough or approximate calculation". So construed, with their limitations recognized, estimates may often be of value to scientists, though they are no substitute for measurements. This subject has been admirably discussed by NEIL STEVENS (1941b) who points out the basic value of estimates in business and economics and the legitimate use of approximate data even in such "exact" sciences as chemistry and physics.

Estimates or approximations are often preferable to no data at all. There are many instances in plant pathology and other sciences in which numerically exact data cannot be obtained; here it is estimates or nothing. Even when exact data can be secured this may be very costly as compared with estimates, and the latter may be preferred when a high degree of accuracy is not essential.

In crop disease loss studies, accurate measurements of loss can be made in experiments designed to determine the relationship between given disease intensities and loss. When it comes to extending these findings to extensive areas the result must be estimates. They will serve the useful purposes indicated in Chapter I if such estimates are extensions derived from measurements and if it is recognized both by estimators and those using the estimates that they are approximations, with certain limits of error but defensible within these limits.

In some cases in the past, plant pathologists have been reluctant to give numerical estimates of crop losses, contenting themselves with loosely generalized descriptive terms. If the estimate is "an opinion based on careful consideration and research", and if limits of error are recognized, it is entirely justifiable to report estimates in terms of bushels, tons, or percentage of crops, and if this is not done the estimate, however carefully arrived at, will have little practical use. The measurements of the effects of disease that are described and encouraged in the chapters that follow are designed to determine approximately the order of magnitude of losses from various diseases, and to narrow the limits of error, to a practical degree, in the loss estimates which must represent the final useful form of our loss statistics.

EXAMPLES OF ESTIMATES CONFIRMED BY OTHER MEANS: -- While time and experience have shown that some of the crop loss estimates of past years have been in serious error, there are a number of other cases in which loss estimates based on adequate surveys and on a knowledge of the relationship between disease intensity and crop loss have been confirmed by independent, objective criteria.

One such example, described by NEIL STEVENS (1940a), is that of wheat bunt, (Tilletia spp.) in which the total loss estimates of Plant Disease Survey collaborators showed the same trends as the official records of smut dockage by federal grain inspectors (Fig. 1). STEVENS and WOOD (1935) give a second example in their comparison of corn losses due to ear rots as estimated by Plant Disease Survey collaborators (Fig. 2) which also showed the same trends as the federal grain inspectors' records of railroad cars with more than 6% damaged kernels. In both of these examples the collaborators' estimates and the inspectors' records agree in trend but cannot be compared as to absolute loss levels, because different disease effects were being appraised, -- total loss on the one hand and percentage of damaged carloads on the other.

As we will see in Chapter VII there are many other independent sources of crop loss information. STEVENS has shown how old local newspaper accounts of the cranberry harvest and records of picker payrolls helped to reinforce his estimates of cranberry losses in past years. It would aid in determining the validity of loss estimates and often strengthen the reliability and increase the acceptability of estimates if more opportunity were taken to bring information from several independent sources to bear on loss appraisals.

THE UNRELIABILITY OF ESTIMATES WITHOUT EXPERIMENTAL BASES: -- When there is no experimental basis for knowing the amount of loss from a plant disease it is a mistake to dignify the opinion of the loss by calling it an "estimate"; more appropriate is the term "guess", which is defined as "an opinion without knowledge or means of knowledge." Certainly that definition applies to many plant disease loss statistics that have been published in the past, with the consequence that when the losses have been investigated experimentally the "estimates" have been found far too low or sometimes too high. Many examples of this could be cited, and the following are typical.

CHESTER (1946b) has reviewed the literature pertaining to estimates of losses from wheat leaf rust. Prior to 1926 this disease was generally regarded as negligible or even beneficial to wheat. Between 1926 and 1936, MAINS, JOHNSTON, CALDWELL, and others measured the loss

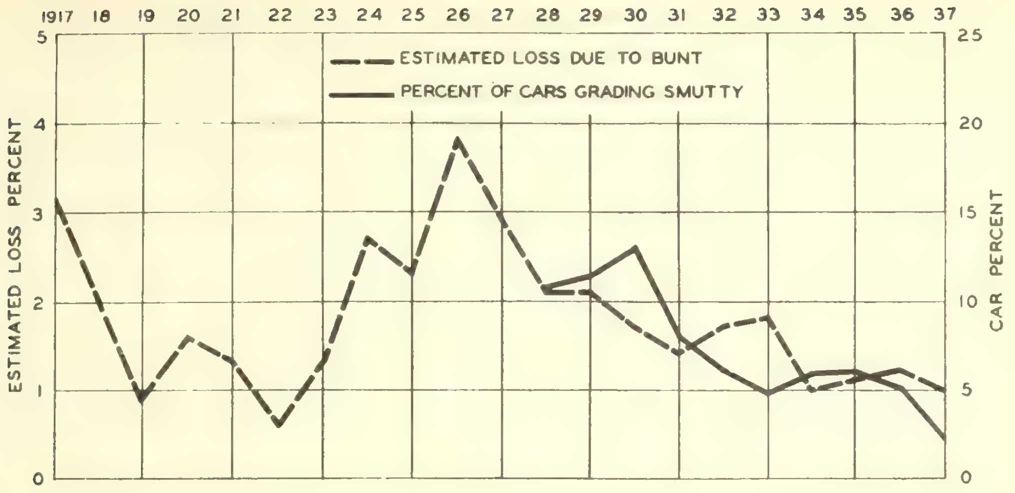
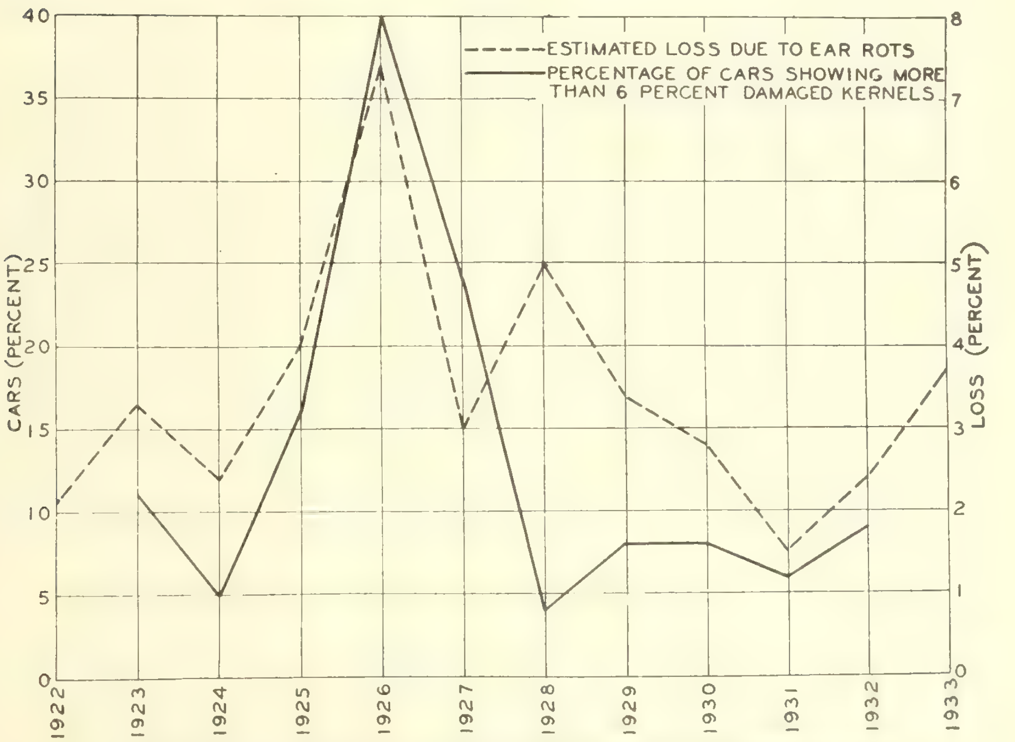


Figure 1. -- Estimated losses from bunt of wheat in United States (reporting area), 1917-1937, and percentage of cars grading smutty at all terminals, 1928-1937. (After NEIL STEVENS, 1940a.)



—— Percentage of cars showing more than 6 per cent damaged kernels.
--- Estimated loss due to ear rots.

Figure 2. -- Percentage oi cars of corn showing more than 6 percent damaged kernels, as indicated by reports of Federal grain inspectors of the Bureau of Agricultural Economics, for the years 1923 to 1932, inclusive. Estimated losses in corn due to ear rots for the United States as a whole, and compiled from reports from collaborators of The Plant Disease Survey. (After STEVENS and WOOD, 1935.)

from leaf rust by means of infection and fungicide experiments, and found that the disease reduces the crop by 35% if it destroys the leaves in the blossoming stage, with greater or less yield reduction associated with earlier or later rust attacks (see CHESTER, 1946b, Fig. 2). All of the earlier reports on leaf rust losses in the Plant Disease Reporter and other publications, and some later ones, must be regarded as gross underestimates in the light of these experiments.

HORSFALL (1930) mentions workers who believed that no damage was caused by powdery mildew of clover but his measurements showed that the disease reduces the crop by 1/3 to 1/4. The U. S. Bureau of Agricultural Economics (1944) indicates that diseases are almost negligible among the factors which lower cotton yields, yet we now have evidence that seedling blight alone, if uncontrolled, reduces the crop by 10 to 20%. EZEKIEL and TAUBENHAUS (1934) have concluded from careful studies that root rot causes a loss of 8% of the Texas cotton crop, and every cotton pathologist recognizes by dead plants and rotted bolls the additional heavy losses from the widespread wilt, bacterial blight, and boll rot diseases.

Gross errors in estimation of crop losses are not limited to those caused by diseases. For example, although WEISS (1940) has stated that insect pest estimates are generally too high, PEPPER (1947) has reported that spray trials with modern insecticides have revealed such remarkable yield increases in potatoes, sweet corn, and alfalfa that it is becoming apparent that older estimates of insect damage were extremely low.

Inaccurate crop loss estimates are harmful. If losses are not recognized or are underestimated, adequate efforts are not made to reduce the losses and they continue as drains upon the national economy. If wheat leaf rust destroyed no more than 5% of the national crop annually, a conservative estimate in the light of present knowledge, the loss in the 35 years, 1900-1935, during which the damage from this disease was considered negligible and little effort was made toward its control, amounted to 1 1/2 billion bushels.

Erroneous loss estimates give plant pathologists and agriculturists in general a false idea of the relative importance of the various crop hazard factors with the result that less important problems receive more attention than more important ones. Underestimates of loss deter manufacturers from producing equipment and materials for loss prevention. Overestimates may lead to wasteful efforts to combat hazards that actually may not justify the expense of their prevention. The many advantages of reliable crop loss information discussed in Chapter I become that many disadvantages when we have crop loss misinformation.

Even when an estimate is reliable within certain limits it may be misused or even metamorphosed into a statement of fact. For example NEAL (1928) states (p. 3) that "the estimated reduction of cotton yield in the United States because of wilt was 350,000 bales in 1925." In the summary of the same paper (p. 46) the statement appears: "the annual loss to the cotton crop in the United States is in excess of 350,000 bales." In this case an estimate for one year has been transformed into a statement of fact for all years. The Plant Disease Reporter, the presumable source of the estimate, places the average loss for the only six years for which data were available at that time at 330,000 bales, with only one of the six years showing a loss "in excess of 350,000 bales."

Another type of misuse of estimates, leading to an erroneous conclusion, is seen in an early paper by RIEHM (1910). In connection with a widespread outbreak of rye rust in Germany in 1891, 7500 questionnaires on rust losses were sent out to growers by the Deutsche Landwirtschaftliche Gesellschaft. Only 400 (5.3%) of these were returned. RIEHM assumed that the rusted acreage reports in this small fraction of returns constituted the total rusted acreage, and he compared this reported rusted acreage with the total estimated rye acreage and derived a figure for rust loss which was trivial.

He concluded by ridiculing SORAUER'S more substantial (and on the basis of present knowledge doubtless more reliable) loss estimates.

REASONS FOR INACCURATE ESTIMATES: -- There are numerous possible causes underlying inaccurate disease loss estimates, the chief of which are discussed below.

Failure to Allocate Loss To Its Actual Cause. -- When several factors may cause crop loss, and particularly when two or more such factors affect a crop simultaneously or in sequence, it may become very difficult to determine the relative and absolute effects of each factor. As a result it has often happened that loss which is actually due to one factor is ascribed to another. This is recognized as a serious fault in insect pest damage estimates (WEISS, 1940) as well as with plant diseases.

Every plant pathologist can cite his favorite examples of mistaken identity of loss factors. Texas root rot in the Southwest is very commonly ascribed to the effects of lightning or alkaline soil. Leaf and stem rusts of cereals are confused. The injury caused by minute insects and

arachnids is often taken to be due to plant disease. Spray injury and fungus leaf diseases are frequently confused. When crop injury from the herbicide 2, 4-D was first seen it was everywhere thought to be due to viruses. The list could be continued indefinitely.

Among the loss factors the practical men of agriculture are most conscious of weather and soil effects, fairly familiar with insect attacks, and understand crop diseases least of all. It is only to be expected that an unexplained crop loss is ascribed to the factors with which the grower is most familiar, and that, as a result, diseases, with microscopic causal agents and effects superficially resembling those due to unfavorable environments, will commonly be attributed to some likely environmental influence or, sometimes, to insects. It follows that estimates of plant disease loss are not infrequently too low and those for the other crop hazards correspondingly too high. Occasionally, with spectacular diseases that cause little injury, the reverse may be true, the disease losses being overestimated.

A striking example of confusion of loss hazard is seen in the analyses of American wheat losses in 1938. In that year (CHESTER, 1946b, p. 20) the disappointing harvest returns in the Southwest were ascribed by different observers to leaf rust, stem rust, excessive moisture, late harvest, insects, hail, and late freezing injury, alone and in various combinations. Difficult as the interpretation of such a situation may be, it should be possible, as one by one hazard factors become better understood, to break these loss complexes down into their several components, and attribute to each its relative partial role in the loss.

Sometimes the problem is one of determining which of two or more similar diseases may be present. YARWOOD (1946a) cites numerous workers who disagree completely regarding the effects of "giant hill" on potato yields, some finding a major or minor yield decrease from the disease while others consider that the condition increases yields above those of normal hills. He considers that one reason for this discrepancy may be that the several investigators are dealing with conditions of different etiologies.

Failure To Appreciate The Destructiveness Of Factors That Are Relatively Constant From Year To Year And Not Spectacular Nor Widely Publicized. -- Diseases that occasionally break out with explosive force are less dangerous, in one respect, than those diseases that are always present to about the same extent. Like rats, weeds, taxes, soil erosion, and the common cold, we have come to consider these constant diseases as "normal" or inevitable. We tolerate them and often forget or never realize that their constancy and our acceptance of it may constitute their most dangerous feature. The occasional spectacular outbreaks, like fires, tornadoes, or plagues of locusts, arouse us to action, and we may often consider that these headline-making hazards are relatively more destructive when, if we average their effects in time and area, we find that the spectacular hazards are doing less damage than the others which fail to attract our attention because they are always with us. Our susceptibility to influence by the spectacular leads us to overestimate the losses from such hazards, while we underestimate the destructiveness of the common, constant ones. We find this true in every branch of plant pathology.

In forestry much more emphasis is laid on fire control than on pest control, yet forest pests destroy more timber than fires. From 1934 to 1943 insects and diseases are estimated to have destroyed 622 million cu. ft. of American timber, while fires destroyed 460 million (WYCKOFF et al., 1947). Similarly, decay of construction timber causes more loss than fire, but its replacement is considered as "normal", and our expenditures for decay control are trivial compared with those for fire prevention. The practical forester regards a few spectacular diseases as diseases. Wood decay, which destroys more timber than any other cause, he considers as normal and inevitable cull. The drain from enphytotic diseases is assumed in "normal forest growth".

In the marketing of agricultural commodities much the same situation prevails. "Few people, even pathologists, realize what enormous quantities of fruits and vegetables are lost through disease, decay, and other preventable causes between the producer and the consumer." Thirty years have passed since SHEAR (1918) made that statement, yet it might have been made today as market loss records will testify. Spoilage claims paid by railroads, board of health produce condemnations, the dump piles behind processing factories, and even the family garbage disposal, all point to the millions of bushels of fresh produce that leave the farm never to be consumed by humans, and all this enormous loss, sometimes half or more of shipments, is considered "normal marketing shrinkage", "part of the game", to be paid for by the consumer.

Turning to diseases in the field, we find a similar disregard of those diseases that are not spectacular or well advertised. This has been the case with leaf rust (*Puccinia rubigo-vera* var. *tritici*) of wheat as brought out in the following quotation from WOOD and NANCE (1938):

"In areas where leaf rust is most important it occurs practically every year to a greater or less extent, with the result that its effect on yield is apt to be overlooked except in epidemic out-

breaks.......Because it occurs to some extent every year it does not focus the attention by a spectacular outbreak as does stem rust. In contrast to the apparent suddenness with which stem rust often attacks, leaf rust is apt to appear early and to develop steadily throughout the season .....Possibly this contrast with stem rust is a chief factor responsible for minimizing leaf rust as a cause of loss...........

"It is probable that if the loss from stem rust were spread over a period of years instead of being concentrated in destructive outbreaks, the disease would attract much less attention than it does. Suppose, for example, that the loss in Minnesota, instead of varying from a trace to 57%, had been 11% annually, which is its present average and the highest for any state. Would it not be considered a routine loss, subject to the 'familiarity that breeds contempt' rather than a calamity to be feared?"

The same "familiarity that breeds contempt" may be seen for many other types of diseases including defoliation diseases of meadow crops (HORSFALL, 1930), bacterial blight of cotton, powdery mildews of peas and some other crops, and root deterioration with premature death such as is common in many crops. It goes without saying that these considerations influence disease loss estimates, even by competent crop appraisers, -- losses from the disease that is spectacular or has a good press agent are fully estimated or even overestimated, while those of diseases that may be quite as destructive, or even more so, but are common and constant, are underestimated.

Lack Of A Disease-Free Standard. -- If a disease is invariably present in a crop the amount of loss which it causes may be underestimated or overlooked because of the lack of a contrast with disease-free plants. For many years this was the case with the latent mosaic of potatoes, as discussed on page 196. Measurements of loss are sometimes difficult because there is no disease-free standard and it is necessary to compare two degrees of disease, rather than diseased with disease-free plants. This has been a difficulty in some of the potato virus loss studies, such as those of MURPHY and McKAY (1924) and of WERNER (1925). If, as some believe, there is invariably a certain amount of decay in the root systems of "normal" plants, we may be failing to detect significant losses from this cause. Foliage diseases in hay crops are further examples.

In all these cases it is possible to measure the loss by experiments in which the invariably-present disease is controlled, using one or another of the techniques described in Chapters VIII and IX. Where this has not been done the reason is usually a psychological one; contrasts between diseased and disease-free crops are not observed in nature; the diseased crop is regarded as a normal one, and therefore the incentive to investigate the losses caused by these omnipresent diseases has been lacking.

Lack Of Negative Data To Temper Reports Of Epiphytotics. -- There is a common and natural tendency for crop reporters to stress the more destructive occurrences of hazard factors and fail to report the absence or minor effects of these hazards. This is recognized as an outstanding weakness of insect pest surveys (HYSLOP, 1927) and applies equally to plant diseases. Severe outbreaks are news; the absence of outbreaks is not. The result is that one can and does get a distorted impression of the importance of diseases from popular or technical crop news publications.

Leafing through the volumes of the Plant Disease Reporter one is impressed by the frequency of articles with such titles as: "An epiphytotic of *Rhizopus* soft rot of tomatoes", "A sudden outbreak of late blight", "Severe damage from corn stalk rots", "Unusual disease occurrences", "Two epiphytotics of *Verticillium* wilt", "High percentage of strawberry fields showing red stele infection", and "Northern anthracnose will cause heavy losses to the red clover hay crop this year" while there is less frequent occurrence of titles such as: "Evidence indicating less loose smut in 1945 than in 1944".

This situation calls for particular care in analyzing the reports, with an effort, which is not always aided by the reporter, to place the unusual outbreaks in their proper setting among seasons or areas in which the disease is minor or negligible. This is assisted by organized reporting in which each reporter is requested regularly to indicate the severity or mildness of various diseases, thus contributing to a file of data in which each unusual oubtreak is given its due proportionate importance, the practice followed until recently by cooperators of the Plant Disease Survey in their annual reports.

Correlation Of Certain Diseases With Seasons Of High Potential Yield, Which Obscures The Actual Losses Sustained. -- Any given ecological factor may favor both crop growth and disease, be unfavorable to both, or favor either one at the same time that it is unfavorable to the other; each of these four combinations has a distinct effect on apparent crop loss from the disease, with the greatest apparent loss resulting from factors which favor the disease and interfere with crop growth.

In general, plant diseases fall into two groups, (a) those which are favored by low vitality in the host plant, such as some of the root decays and wilts, and foliage diseases that are caused by organisms of only moderate virulence, and (b) those diseases that develop most aggressively on plants in a high state of vigor, such as rusts, many downy mildews, and bacterial diseases of succulent tissues. In the former case low yields are made lower by the disease, and this leads to an exaggeration of the loss caused by the disease, while in the latter case the disease loss is more or less compensated for by the high potential yield of the vigorous crop, with the result that losses from such diseases are underestimated or even disregarded unless the disease reaches ruinous proportions. The plant pathologist sometimes even finds himself in the difficult position of defending a substantial loss estimate in a crop which has actually yielded more than "normal", though less than its potential yield, during a very favorable growing season.

This situation is most characteristic of areas in which some one environmental factor is the outstanding limiting condition both to crop yields and to disease development. In dry-land areas this factor is commonly rainfall. During years of abundant rainfall potential yields are increased, perhaps even more than enough to offset the increased loss from rust or other diseases that are simultaneously favored by the increased rainfall. In areas where soil is low in fertility, fertilization may increase yields enough to minimize or offset the attendant increase in loss from diseases that are favored by soil fertility. A few examples will bring this out.

In 1941 speckled leaf blotch of wheat (Septoria tritici) was epiphytotic in winter wheat areas, destroying 40 to 50% of the foliage, but the outbreak occurred in a cool, moist spring and the widespread damage was somewhat obscured by the favorable effect of the abundant rains (CHESTER, 1947). EZEKIEL and TAUBENHAUS (1931, 1934) have found that Texas root rot of cotton is most destructive in years of high rainfall which increases the potential yields so as to mask the full yield-reducing effect of the disease.

In 1938 the most severe recorded epiphytotic of leaf rust was estimated to have reduced the Oklahoma wheat crop by 29%. In this well-watered year the average yield was 11.0 bushels per acre as compared with 11.2 bushels for the preceding 10-year average, which was in a cycle of drought. Many considered the rust-ridden crop of 1938 as practically "normal", failing to appreciate the potentialities of this crop, with abundant rainfall, had not leaf rust duplicated the crop-depressing effects of Oklahoma's arch-enemy, drought, during that year (CHESTER, 1946b). The same year JOHNSTON in Kansas wrote: "The leaf rust damage will probably be underestimated because of ample rains which will raise the general yield level", and TEHON found the same to be true in Illinois.

The practical men of agriculture find it difficult to accept estimates of substantial losses from disease in years in which yields are higher, or at least no lower, than average. The effect is for plant pathologists themselves to underestimate the losses rather than expose themselves to disbelief. Under such conditions, if reliable loss estimates of plant pathologists are to be secured and accepted they must be supported by experimental evidence, such as can be obtained by comparing yields of disease-resistant and -susceptible varieties or those of susceptible varieties with and without chemical protection, during seasons of this type.

Correlation Of Certain Diseases With Freedom From Other Hazards. -- If, as sometimes happens, there is a positive correlation between the yield-depressing effect of a disease and the yield-elevating effect of freedom from another disease or hazard, the two effects may cancel one another, or if the second effect be greater there may actually be a net yield increase associated with the disease. The following two cases are in point.

CLINCH and MCKAY (1947) in Ireland found that mild strains of potato virus X produced no significant decrease in potato yields, but rather a tendency to increase yields. In these tests there was an attack of late blight late in the season. The X-virus-infected potatoes ripened prematurely and thus escaped the more serious menace of late blight which significantly lowered the yields of the virus-free checks. The same "beneficial" effect of the mild X-virus strains or any other disease or factor which accelerates maturity might be expected to reduce losses from early frosts.

YARWOOD (1946a) in California observed that potatoes with "giant hill" were more resistant than normal potatoes to "decline", a serious yield-depressing factor in his experiments, caused by species of Verticillium and Rhizoctonia, as well as having some resistance to early (Alternaria) and late (Phytophthora) blights. As a result, the giant hill plants yielded more than plants without the giant hill defect, which suffered losses from these other diseases.

We can readily see from these reports the importance of a complete analysis of yield factors in order properly to interpret the role of any one of them. We cannot conclude that these factors, X-virus in the one case and giant hill in the other, are harmless or beneficial. In both cases other workers, under other conditions, have demonstrated their harmfulness. It is clear that disease loss studies that do not consider the whole complex of yield factors may produce quite

misleading and erroneous loss appraisals.

Lack Of Correlation Between Field Loss And Lowered Quality. -- An estimate of loss due to a plant disease must include all of the losses sustained, both in the field and in shipment, storage, and marketing. Appraisal of loss at one of these stages without consideration of the others may result in serious errors in loss estimates. There are two contrasting types of cases.

The first case is that in which the field loss is greater than that indicated by the condition of the harvested crop. If we rely too heavily on grain inspection records for our loss estimates in cereals we may find that we are overlooking serious field losses that are not adequately brought out in bin or carlot inspections. When wheat, for example, is well cleaned, many bunt balls or nematode galls which it may contain are removed. Examination of this grain will then suggest a much smaller amount of disease in the field than was actually present.

Table 1. Losses from wheat bunt (Tilletia spp.) and wheat nematode (Anguina tritici) as seen in grain inspection, compared with field losses.

Wheat bunt (HASKELL and BOERNER, 1931)				Wheat nematode (CHU, 1945)	
Number smut balls in 50 gm. seed	Grade	Dockage (¢/bu.)	Average % of smut in field	% weight of galls of total weight of seed	Actual yield reduction
0	Clean	0	1.5	01 - .09	5%
2-	Clean	0	3.8	2. - 2.9	30%
2-5	Light smutty	1-2	6.6	6. - 6.9	54%
5-10	Medium smutty	2-10	8.0	8. - 8.9	69%
10+	Heavy smutty	20+	11.8		

Representative data on this point are given in Table 1. Wheat is graded "light smutty" if it contains 2 to 5 bunt balls in 50 gm. of seed. This would indicate only .04 to .16% smut in the field were it not for the fact that many bunt balls are removed by cleaning the grain. In this case there would actually be 6.6% smut in the field which equals approximately 6.6% yield reduction. Even more striking is the case of wheat nematode where 30% loss in the field results in only 2 to 3% nematode galls in the grain. The extreme case is that of loose smut where there is no indication of disease in the grain even when there is a high percentage of loss in the field.

Reports of the Federal grain inspectors are important sources of information on cereal disease losses. Since grain inspection indicates much less loss than actually occurs, estimates of loss based on grain inspectors' reports are likely to be much too low. Also, if grain is smutty or otherwise diseased the grower is penalized and the purchaser exerts pressure on the grower to eliminate the disease. With a disease such as loose smut of wheat there is no dockage, since the disease does not show in the grain, and the purchaser is unconcerned. The result is that growers tend to attach disproportionate emphasis to diseases that result in dockage, and actually they will disregard serious loose smut losses while striving to reduce less consequential bunt losses. This situation shows how discrepancies in field loss and condition of the harvested product tend to distort loss estimates.

There are cases of the opposite sort, in which negligible field loss from a given disease is followed by a serious loss from the same disease later. McNEW (1943j) brings this out strikingly in the case of tomato anthracnose (Colletotrichum phomoides). A very few anthracnose-infected tomatoes in the crop will produce such a high mold spore count in canning that unless these few diseased fruits are removed the pack will be declared "unfit for human consumption" according to government standards. Removal of these few diseased tomatoes doubles or triples the cost of picking, since if even a small amount of anthracnose is present every fruit must be carefully inspected. The necessity for trimming the fruits before processing further increases the cost. If tomato anthracnose loss is appraised in the field purely on the basis of percentage of sound fruits, as has frequently been done in the past, the loss estimates will be far too low.

In plants that are grown in seedbeds and then sold as transplants it often happens that little or no seedbed loss is followed, even unbeknown to the seedbed grower, by serious secondary losses in the plantings of the purchasers. This is frequently the case with late blight (Phytophthora) and bacterial leaf spot (Xanthomonas vesicatoria) of tomatoes, bacterial leaf spot (X. vesicatoria) of peppers, and root knot (Meloidogyne spp.) of vegetables, ornamentals, and woody plants. Here, too, appraisal of the diseases in the seedbeds alone leads to gross underestimate of losses.

Subjective Errors Of Judgment Due To Inadequate Or Biased Training And Experience. -- This subject has been well discussed by P. R. MILLER (1946) who points out that a large majority of growers unintentionally either exaggerate or minimize disease losses in about equal proportions. Exaggeration may be due to hope that this will call attention to disease and that price increases will result. A minimizing of losses may be caused by the grower's fear that he may be regarded as a poor farmer if it is known that his crops have suffered severe losses from disease.

Agricultural scientists are prone to overestimate losses from the hazards with which they are most familiar or in which they are most interested, and to underestimate others. It is only natural for agronomists to lay particular stress on soil and climatic factors, entomologists on insects, and plant pathologists on diseases. Plant pathologists are sometimes poor estimators because of a tendency to overemphasize the diseases with which they have personally worked. Those in charge of disease-control "action programs" sometimes may intentionally exaggerate the importance of a disease to stimulate adoption of control practices by growers who might otherwise fail to use them.

CHESTER (1945b) has distributed a questionnaire asking plant pathologists to estimate the losses from 19 common plant disease situations, where in each case there was experimental evidence of the amount of loss caused. The average error was 16.6%, and there were almost exactly as many cases of underestimates as overestimates. The most marked overestimates were for diseases of a more or less spectacular nature, which have been well publicized, e.g., sugarcane mosaic and cotton root rot. In the case of corn smut (*Ustilago maydis*), a very common disease the loss from which has been carefully measured in a number of well-conducted experiments by different workers, all of whom found that a smutted corn stalk yields about 2/3 as much as a normal stalk, the loss estimates ranged from 1% to 60%, and nearly as wide ranges were obtained for the potato virus diseases, tobacco mosaic, tomato *Septoria*, and other defoliation diseases.

Plant disease losses are usually badly underestimated by those economists who lack training in plant pathology and whose estimates, in turn, are based on data from practical men of agriculture who also often lack this training. The following (Anon., 1926) are economists' estimates of average losses due to all diseases in the crops indicated, while in parentheses are given the plant pathologists' estimates of average loss from all diseases in the same crops, taken from the very conservative estimates of the *Plant Disease Reporter* (1917-1939 average): corn, 0.4% (9.8%); wheat, 5.2% (13.4%); oats, 2.8% (8.8%); apples, 4.6% (13.4%); barley, 2.7% (6.3%); potatoes, 5.6% (18.2%); cotton, 1.0% (14.5%); and tobacco, 1.5% (23.5%). Economists' estimates, as those of plant pathologists, are often unduly influenced by spectacular or obvious hazards, as seen in the cotton statistics (Bur. Agr. Econ., U. S. Dept. Agr., 1944) where estimates of losses from the boll weevil usually are between 10 and 30% of the crop while those of cotton diseases are almost negligible. Overestimates of loss are also sometimes due to anxiety stemming from reports of losses in neighboring districts.

Errors Due To Non-Representative Sampling: -- If loss appraisals are made by, or with the aid of, county agricultural agents, losses may be underestimated, since these men deal primarily with the best farmers, who make full use of agricultural science in preventing losses. If the estimates are made by, or with the assistance of, Farm Security agents, the reverse may be true; losses are overestimated because these men work chiefly with small-scale, handicapped farmers.

Unless a purely random method of sampling is employed there is a tendency for a plant pathologist's disease loss estimates to be biased by a complex of several factors. He is likely to stress those problems that are brought to his attention by others at the expense of problems which he must go out and find. His reliability is likely to diminish in proportion to the distance of disease problems from his headquarters. Reported disease outbreaks of purely local significance may be mistaken to be representative of large regions. In surveying for disease the observer will be most influenced by conditions on farms adjoining highways, where disease is likely to be under better control than on more remote farms. If his time is at a premium, he may not be able to sample large farm fields adequately, and may then be unduly influenced by roadside conditions in which diseases, like growth, show the well-known "border-effect". Like the county agent, the plant pathologist in apt to be in contact with too high a proportion of the best farmers, i.e., those who have enough interest in plant disease to ask advice.

Correction of the bias that results from such influences can be made if the estimator is conscious of his bias and its causes. Non-representative samples still have value if they can be weighted to correct for recognized error. The size and type of sample of a crop within a field, or of fields within an area, is considered separately in Chapter V, and here it is only necessary to point out that extensive studies on sampling procedures already provide us with the necessary

background of information to enable us to obtain representative, unbiased data. It is an object of this book to encourage the use of approved sampling methods in disease loss appraisal.

Errors Due To An Unsuitable Method Of Appraisal. -- To estimate the losses from plant diseases correctly it is necessary that the estimator have in mind all forms of loss and the relative role of each. If attention is limited to only one aspect of the disease, the loss may be seriously underestimated. It would be a mistake, for example, to consider the percentage of seedlings destroyed by damping-off as a loss percentage. This must be corrected for at least two factors, the additional loss from injury in plants which survive, and compensation for seedling loss by growth of adjacent plants, especially where a heavy seeding rate has been used. Both quantity and quality loss features must be considered. Loss may be partly compensated for by reduced costs of harvesting and handling a diseased crop. While many observers consider the percentage of bunted tillers in a wheat field as equal to the percentage of yield reduction due to bunt, MOURASHKINSKY in Russia has reported that bunt also kills some plants, increasing the loss figure.

These few examples serve to bring out the fact that errors in loss estimates will result unless the appraiser is quite familiar with the disease itself, and with the various factors which tend to increase or decrease the true loss figure as compared with the apparent loss seen in some one conspicuous aspect of the disease. His method of appraisal must be appropriate if the loss estimate is to be reasonably accurate.

Errors Due To Duplication And Summation Of Loss Estimates At Different Stages In The Marketing Of A Crop: -- P. R. MILLER (1935) has indicated this as a source of error in estimates, illustrated as follows: "If 100 bushels of oranges were inspected at the wholesaler's and 5 bushels were decayed, and the remaining 95 bushels were inspected at the retail store and 10 bushels were decayed, the total loss from the 100 bushels would be 15 bushels or 15%. However, the recorded loss would be 5% (5 bushels loss from 100 bushels) in case these oranges were inspected only at the wholesaler's; or 10.5% (10 bushels loss from 95 bushels) if inspected only at the retailer's. If inspected at both wholesaler's and retailer's without a knowledge of its being the same shipment, the recorded loss would be 7.6% (15 bushels loss from 195 bushels). Obviously the recorded loss in any of these cases would be less than the actual loss".

There is the possibility of other cases in which the damaged produce is not removed from the shipment. If the loss is estimated at two points in the marketing of the produce and if it is concluded that there was X% loss at the first point plus Y% at the second point the resultant figure would be too high, since X and Y are the same loss.

Lack Of An Experimental Basis For Estimation. -- In most cases the amount of loss from a plant disease cannot be judged merely by inspection of a diseased crop. Often the injuries are so subtle that a trained observer is misled. The only way of obtaining an accurate estimate, in such cases, is by the use of the results of loss measurement experiments.

Before the measurement of losses from wheat leaf rust, plant pathologists commonly underestimated this loss by 1000%. HORSFALL'S (1930) measurements of hay disease losses showed that these are very much greater than had been suspected. The same has been seen in the case of potato latent mosaic (see page 196). One form of gas injury to plants is called "invisible injury", and this form of loss was unrecognized until measurements showed that growth is retarded by amounts of gas that are too small to produce leaf symptoms. The measurements of VALLEAU and JOHNSON (1927) showed that the value of tobacco which was infected with mosaic at setting time was reduced 25.1%, "a difference which could hardly have been predicted at cutting time". In the case of pea seedling disease, McNEW (1943e) has found it almost impossible to detect a loss of 10% or 15% by visual observation alone, yet this is much more than the minimum amount of loss warranting control measures. Lack of measurements of decay often lead to excessively low estimates of timber cull, according to WEIR (1918), and WYCKOFF et al. (1947) point out that there is no experimental basis for estimating the loss from many forest diseases. On the other hand, the failure to consider the regenerative abilities of plants and the compensation for the loss in healthy plants adjacent to diseased ones (page 318) leads to overestimates of loss.

These examples, which might be multiplied manyfold, show clearly that plant pathologists cannot trust their eyes or even their experienced judgment in estimating disease loss where there is no experimental basis for knowing the amount of loss caused by a given intensity of disease.

Fear Of Prejudicial Effect Of Loss Reports On Agricultural Industry. -- Occasionally one hears of resistance to the publication of disease loss information for fear that it may reflect unfavorably on a producing area. KNAPP (1927), for example, has indicated that in Holland it is considered inadvisable, from the standpoint of the export trade, to publish statistics on plant dis-

eases. The many local check lists of plant diseases and the long-established practice of the United States and Canadian Plant Disease Surveys of disseminating this type of information, indicate that suppression of plant disease statistics fortunately is not the rule.

At the Root Knot Nematode Conference in 1937 (BARSS et al., 1937) the question was raised whether the publication of data on the distribution of this pest might not make trouble for producers, interfering with their sales. H. A. EDSON of the Plant Disease Survey replied that this is a familiar problem and that it is possible for disease data to be sent to the Survey, not for publication, but for consultation by scientists. He then said: "There is some deliberate suppression of information, due (1) to fear on the part of commercial interests, and (2) to the fear of quarantine regulations, especially of state quarantines. Taking a wide view, the best course would seem to make all information immediately available."

Dr. EDSON'S view is to be indorsed; the solution is not to suppress needed information but to educate those who would suppress it. Suppression of plant disease distribution and loss data is detrimental to the many valuable uses of such data as outlined in the preceding chapter.

Chapter III

SOME PRINCIPLES AND PROBLEMS OF PLANT DISEASE APPRAISAL

DESIDERATA OF METHODS FOR APPRAISING PLANT DISEASE LOSSES: -- To be most useful the methods for appraising plant diseases should meet certain requirements. In particular they should be concerned with losses, not merely disease intensities, and they should be comprehensive, complete, accurate to a practical degree, comparable, and objective. These qualifications are taken up individually below.

Disease Appraisal Methods Should Measure Disease Intensity And Translate This Into Crop Loss. -- If a disease causes total destruction of plants or of the marketable parts of plants its appraisal may be comparatively easy, since there is agreement between disease incidence percent and loss percent, and simple counting may suffice to determine both incidence and loss. It is quite natural, as P. R. MILLER (1946) has indicated, that it is for such totally destructive diseases that we have the most reliable loss estimates, and the same thing has been observed in attempts to secure livestock morbidity and mortality data (Anon., 1948).

The preponderance of available data on the importance of plant disease are prevalence or intensity data. In the better reports, e.g., those of TEHON (1927) and TEHON and STOUT (1930), there are data on both prevalence (percentage of plants affected) and intensity (degree of attack on individual plants), and these two values are combined to give an overall index of disease attack. This is a measure of severity of disease attack; for example, in dealing with foliage diseases it gives a measure of the average amount of leaf tissue destroyed, but it is not a measure of commercial loss, as the authors clearly point out. Their interest lay primarily in a study of the epiphytology of certain diseases over a period of years, and for this purpose their disease severity data were entirely adequate. They have even called attention to the fact (1930, fig. 25 and pertinent discussion) that in the cases of peach scab and brown rot, scab (Cladosporium carpophilum) showed the greater intensity but brown rot (Monilinia fructicola) produced the greater commercial loss.

Such data have great value in interpreting the effect of weather on disease destructiveness and from some other pathological points of view, particularly when they are as complete and objective as in the cases cited. While, in their present form, they do not translate disease intensity into loss, it should be possible, once disease intensity-loss ratios have been determined experimentally for each disease in question, to convert these basic data into loss estimates. Whenever experiments have shown the relationship between given disease intensities and consequent losses, there is opportunity of going back through the records of disease intensity and, by applying loss-conversion factors to the intensity data, of obtaining the loss statistics which have almost exclusive importance for the useful purposes outlined in Chapter I.

Meanwhile it is clear that if these useful purposes are to be served we cannot be content with limiting disease appraisal to disease severity. Reliable disease intensity data are necessary but these are only half the requirement; we must meet the whole requirement by finding and using means for translating disease intensity into disease loss, and this must be done not only for those cases in which there is a simple numerical relationship between attack and loss, as with totally destructive diseases, but also for the more common and more difficult cases in which the crop is injured but not destroyed, in which there is a more complex relationship between disease intensity and the loss it occasions.

Disease Appraisal Methods Should Be Comprehensive. -- They should embrace all major diseases of all major crops, otherwise the assembled data will have only limited value for the important purpose of comparing loss hazards in order to determine the wisest course in research, educational, and action programs.

This is an ambitious objective but not a visionary one, although years of effort and the cooperation of many plant pathologists will be required. If each pathologist, in his own specialized field of research, would consider the determination of losses a standard part of the thorough investigation of any plant disease, worthy of as much attention as he now gives to nomenclature of pathogens, pathological anatomy, or other academic phases of his studies, and if a very few pathologists would undertake the acquiring and synthesis of loss data as a major project, the task could be accomplished and the potential benefits discussed in Chapter I would be realized.

Disease Appraisal Methods Should Have A Practical Degree Of Accuracy. -- The end-products of disease appraisal are estimates. The value of reliable estimates, as contrasted with exact measurements, has already been discussed (page 210). There is no need or practical possibility for plant disease appraisal figures to have the degree of accuracy that is required, for example, in the auditing of bank accounts. As one seasoned pest appraiser puts it: "You don't need to use a micrometer caliper in making a gate peg." At the other extreme, the gross errors

in loss estimation such as were mentioned on page 212 serve no useful purpose and may be harmful. "To the uninformed who take them at face value, crop loss estimates are very impressive but equally dangerous" (P. R. MILLER, 1946). Between these extremes there is a golden mean, where loss estimates are sufficiently accurate to be useful, reliable within moderate limits, but without reaching an uneconomical degree of precision.

The width of these limits depends on the appraiser's judgment. They can be made narrower by more extensive sampling and more thorough experimental testing of disease intensity-loss ratios. In most cases if an estimate is correct within a ±15% margin of error it should be suitable for practical purposes. As an example, corn smut reduces the yield of smutted stalks an average of 33%. If the loss in individual appraisals varies between extremes of 28% and 38% (± 15% variance from the mean of 33%), the range is still sufficiently narrow to enable us to place smut in its approximate rank among corn diseases and, by applying this figure to survey data, to estimate the bushel loss from corn smut with reasonable accuracy, sufficient for the purposes of loss estimation. This would be defensible and would be preferable to the extreme guesses of the injury from corn smut submitted by collaborators of the Plant Disease Survey (page 217) ranging from 1% loss to 60% loss.

The proposed figure, ±15% margin of error, is arbitrary, and is given only to suggest a desirable order of magnitude of the permissible error. In some cases the range would necessarily be wider because of variability of loss ratios for a given disease or great difficulty in determining losses. In other cases, as with the cereal smuts, it might be very much narrower. The width of the permissible range of error of estimates depends on several factors, including the experimental basis for estimation, variability of loss from given diseases, purposes of the estimate, and practical considerations. Increasing the precision of estimates is expensive and is not warranted beyond the degree of precision that gives reasonably dependable results.

Disease Appraisal Methods Should Be Comparable From One Worker, Location, Or Season To Another. -- Two stages are involved: (a) comparable or uniform practices in appraising disease intensity, and (b) the use of standard, experimentally determined conversion factors to translate disease intensity into disease loss.

We have already made a little progress in the first of these objectives. The modified COBB rust scale (see page 244) has been used by nearly all American workers for appraising cereal rust intensities, for some 30 years. There is some lack of uniformity in the manner in which this scale is used, but even with this limitation the reports of rust intensities in terms of a standard scale greatly increases the usefulness of rust reports, making it possible for one worker to have a fairly clear conception of rust situations appraised by others, and permitting the summarizing of rust data from many locations and workers in tables of comparable data, as is regularly done with data from the Uniform Rust Nurseries.

MCKINNEY"s index of infection (see page 253), a standard method of combining disease prevalence and intensity into a single figure, has lately been adopted by many workers, dealing with a variety of diseases, and represents another important step toward uniformity in reports. HORSFALL and HEUBERGER (1942a), applying this method to a tomato defoliation disease, found that it was statistically reliable and gave very similar results when used by three independent observers.

In the various cooperative experiments in plant disease control, involving workers in several States, a uniform method of reporting disease intensity is usually adopted. In cooperative root knot nematode work, for example, the cooperators are each furnished a photographic scale of several degrees of root knot severity, and this is used as a basis for a uniform numerical system or reporting data.

But there are far too few instances of disease intensity reports of a uniform type. The Plant Disease Reporter contains a great majority of reports which can never be compared or synthesized with any satisfactory results because the observers have either failed to mention use of any recognizable standard of disease intensity measurement, or have used original standards that have meaning only for themselves.

The second stage in the evolution of a comparable system of disease appraisal consists of the development, experimentally, of conversion factors that permit the translation of disease intensity into disease loss. Many of these have already been derived; many more others await development. Adoption of their use should not be too difficult a problem, since they need to be used only by those who desire to secure loss estimates. The basic data are those on disease intensity, which may be gathered by many observers who are not concerned with the calculation of loss estimates. Here the principal problem is the encouragement of research by specialists on each of various diseases, aimed at determining disease intensity-loss relationships, and the research on a sufficiently broad and accurate basis so that the conversion factors derived will be acceptable and considered reliable by those who wish to use them in making loss estimates.

Disease Appraisal Methods Should Be Objective. -- They should be so set forth that their use will not be influenced by the bias or point of view of the observer. This can be accomplished if a standardized procedure of randomized sampling is followed, if the scaling of disease intensity is done by use of a standard disease intensity scale, if the results are summarized in a uniform fashion, and if disease intensity data are converted into disease loss statistics by use of generally accepted, experimentally derived conversion factors.

We have seen the great discrepancies between reported loss estimates, and have recognized that personal bias is a leading factor in producing these discrepancies. Bias is inevitable, and the truly scientific observer recognizes bias as an ever-present danger in his work. Just as he welcomes an opportunity to test his research results on "unknowns", he will welcome objective criteria for disease intensity and loss appraisal. It is an important aim of the present study to contribute toward the adoption of such objective criteria at each step in the procedure of disease loss appraisal, and these several steps are discussed in detail in later chapters.

Disease Appraisal Methods Should Embrace All Forms Of Disease Loss. -- With many plant diseases the loss which they cause is complex, consisting of several components, each of which must be measured and given its proper place in estimating the overall loss. The quantity of yield is perhaps the easiest of these components to appraise, and often is the only one considered. Quality of the harvested crop is next in importance, though often disregarded in loss estimates, and this is considered separately in the following section. Still less commonly considered are such effects of disease as increasing the cost of handling, harvesting, and marketing the crop, and the cost of direct disease control measures in those cases in which there is no loss in the crop itself when the disease is controlled. Seedling diseases sometimes cause no direct reduction in yield, the loss factor here being the waste of seed required to produce a satisfactory stand or the expense and disadvantage of making a second planting.

Bacterial blight (Xanthomonas malvacearum) of cotton is a case illustrating the complexity of loss. The disease destroys seedlings, necessitating increased planting rates, seed treatment, or replanting. It injures stems, depressing the vigor of growth. It partially destroys the leaves, reducing photosynthesis, with consequent reduction of fruit formation, although if defoliation from the disease is very late in the season it may be regarded as an advantage, facilitating harvesting. The disease attacks the bolls, and while it does not usually destroy them, it opens the way for boll-rotting fungi to enter the bolls and weaken or destroy the lint, resulting in both lowered yields and quality of the harvested crop. Long and thorough study, and measurement of the loss fractions due to each of these components, is required before a reasonably accurate appraisal of the loss from this disease is possible.

Whether loss be simple or complex, determined with ease or difficulty, it is clear that loss appraisal practices must consider all of the loss components, from planting to final disposal of the crop. Because some cases are difficult to analyze is not a signal for a defeatist reaction to the whole problem, but rather a challenge to analyze these difficult cases, since the discovery of the amounts of loss in such cases may entirely change our conception of the damage being done by different diseases, and may justify new efforts and new approaches to the control of those disease problems where the loss is serious, though complex and obscure.

CONSIDERATION OF BOTH AMOUNT AND QUALITY OF THE CROP IN LOSS ESTIMATES: -- Most commonly loss estimates are based on the volume of yield alone. This may result in estimates that are far too low, when, as often occurs, the quality as well as the quantity of the crop is reduced by disease. An outstanding example is the effect of stem and leaf rusts on wheat. In his extensive sulfur-dusting experiments to measure rust damage, GREANEY found that lowered grade or quality, sometimes to the point where the grain is unfit for milling, is a major aspect of rust losses.

Loss of quality as a result of tobacco mosaic has been studied by a number of workers (VALLEAU and JOHNSON, 1927; McMURTREY, 1928, 1929; WOLF and MOSS, 1933; THUNG, 1940; and JOHNSON and VALLEAU, 1941). McMURTREY'S data are typical. He found that when tobacco became infested with mosaic one month after transplanting the acre yield was reduced 25%, but the quality was so lowered that the price per 100 lbs. dropped 40%, reducing the acre value by 54.5%. Here the reduction in quality was even more important than the yield reduction. Objectivity in the tests was secured by having the quality graded by two tobacco buyers who did not know the experimental treatments.

There are some cases in which quality reduction may be the only form of loss. This is true of diseases that disfigure or blemish fruit without either reducing yields or contributing to spoilage, such as scab of peaches, flyspeck (Leptothyrium pomi) of apples, or mild cases of apple blotch (Gloeodes pomigena).

The quality factor may be a difficult one to appraise, as pointed out by DUNEGAN (1945), since the loss depends on grading or culling practices that vary from one season to another. In years of bumper crops the fruit is graded more critically, and there is a greater penalty for low quality than in years of light crops. DUNEGAN cites bacterial spot (Xanthomonas pruni) of peaches, in which case during some years fruit with numerous spots sells readily while in other years one or two spots are considered a sufficient cause to throw the peach into the cull pile. The relation between lowered quality and market quality requirements is quite involved, and a more extended account is reserved for discussion in connection with the economic effects of plant disease (Chap. XII).

Nursery Stock And Ornamentals. -- Nursery stock constitutes a special case of quality requirement since it is subject to health inspection before sale, to prevent spread of disease. It is not infrequent for large lots of nursery stock to be disqualified for sale because they are carrying, or are suspected of carrying, disease which may have led to no other form of loss in the nursery. As a rather extreme illustration, a nursery was prohibited from selling 50,000 marketable peach trees because a single mosaic-infected tree was found in the nursery. When the trees were released from restriction a year later they were too old for sale and the loss was total. In cases of this kind the loss depends entirely on the inspector's rulings, and is independent of field loss or yield reduction.

Ornamentals constitute another special case of quality requirement, in which the aesthetic value of the plant dominates over the other loss factors, and may have little relation to the health of the plant in the ordinary sense. If the petals or leaves of a rose or lily plant, for example, are even slightly spotted, the plant becomes unsaleable and the loss is total, even though the disease is actually doing little or no harm to the plant as an organism.

Of all types of crops, our data on losses of ornamentals are least complete, and the chief reason for this may be the peculiar importance that is attached to the appearance of these plants, rather than volume of production. Here a study of sales experiences rather than of culture of the crop may provide the most useful information on losses. At present we have little more than isolated instances by which to evaluate losses in ornamentals. A valuable contribution to plant pathology, from the standpoint of this book, could be made through a detailed, statistical study of the economic effects of diseases of ornamental plants.

Gross Damage As The Product Of Disease Prevalence X Destructiveness. -- The loss caused by a disease is a function of its injuriousness to individual plants or fields and of its prevalence over the appraisal area. If a long-time average loss is to be estimated, the prevalence of the disease from one year to another must also be considered. Long-time average loss estimates are most useful in planning research, education, and regulatory work, and accordingly the estimates normally will be concerned with all three of these factors.

It frequently happens that a disease which is most destructive in certain locations or years is not actually the most damaging from a broader point of view. In potato, for example, the virus diseases leafroll and yellow dwarf are much more destructive to individual plants or to heavily infested plantings than are the potato mosaics. Usually the mosaics are so much more prevalent, however, that their net effect in reducing yields is greater than that of the more spectacular virus diseases. Similarly, of all the organisms causing cotton seedling disease in the Southwest, the anthracnose fungus, Glomerella gossypii, is most virulent, and most rapidly destroys the plants. Yet this fungus is not nearly as prevalent as somewhat less aggressive cotton seedling fungi, such as Rhizoctonia solani and Fusarium moniliforme, so that these latter are considered to be more important than the anthracnose fungus in causing seedling loss in this area.

In many references to disease loss, given in justification of the economic importance of a disease, there is mention of the estimated loss in certain years during which the disease was epiphytotic, without reference to the years in which the disease was inconsequential. It would be misleading to point to the estimated 55 million bushel loss of potatoes from late blight in 1938 without noting that in none of the nine years preceding was the estimated loss as great as 10 million, or better, giving the average loss for the 25 year period for which estimates are available.

Individuals, growers or agricultural scientists, are likely to lay much greater stress on the local destructiveness of a disease than on its prevalence; they may be uninformed of the latter. The consequence is a tendency to overrate the importance of diseases which attract attention because of their locally devastating attack, but actually are not sufficiently prevalent to warrant concentrated work at the expense of other diseases which are not quite so noticeable but, because of their widespread occurrence, are actually causing greater loss.

INTERPRETATION OF THE PARTIAL AND JOINT EFFECTS OF TWO OR MORE CONCOMITANT LOSS FACTORS: -- When two diseases or other factors attack a crop simultaneously the loss is usually greater than that caused by one factor alone. These cases frequently lead to serious errors in estimating loss since, without loss measurements, there is a tendency to lay disproportionate stress on the destructiveness of one of the factors, particularly the one that is most obvious or the most recent in appearance, or the factor to which the observer, through training and experience, has given greatest attention in the past. There are many cases of recorded loss data in which it is now difficult or impossible to ascribe the loss to its true causes because more than one major loss factor has been functioning.

Any factor which leads to variability of yields from year to year is harmful, even though the long-time yield average may be satisfactory. This phase of the economics of plant disease is discussed more fully in Chapter XII, but here it should be pointed out that some diseases tend to increase the variability of yields while other diseases contribute to more uniform yields by largely confining their attack to what would be bumper crops. In this special case, two diseases of a crop acting over a period of years and in various locations may have an additive effect in increasing variability of yield or their effects may be in the opposite direction, actually stabilizing yields, as pointed out by HARTLEY and RATHBUN-GRAVATT (1937). If one disease is favored by hot weather (as potato tipburn) and another by cool weather (as potato late blight) their combined effect on yield variability will be less than that of either disease alone.

If two loss hazards do not regularly occur together it may be comparatively easy to discriminate their respective effects in producing loss, since it will usually be possible to find or produce plantings in which either one of the hazards, alone, is present. By comparing the loss produced by each hazard with the loss from their combined effect, the partial role of each can be determined. The problem becomes more difficult when the two hazards are almost invariably present together.

A most useful procedure in the latter case is the experimental determination of loss using varieties of the crop that are resistant to one hazard but susceptible to the other. This has been done with the potato viruses and with the cereal rusts. In the case of potato, practically all plants grown, except new seedlings, are infected with the latent mosaic virus. Whenever they become attacked by a second disease the loss-effect is the result of two diseases combined. As MURPHY and MCKAY (1924) showed, this double infection makes it difficult to interpret many of the data on losses from potato viruses.

This problem was solved by SCHULTZ' discovery of the potato seedling 41956, which is resistant to latent mosaic but susceptible to other viruses, and using this seedling SCHULTZ and BONDE (1944) have been able to determine the separate and combined effects of the two viruses that together produce mild mosaic. Others have applied the same technique to other potato virus complexes.

For many years wheat in America was commonly attacked simultaneously by leaf and stem rusts (<u>Puccinia</u> <u>rubigo-vera</u> var. <u>tritici</u>, <u>P.</u> <u>graminis</u> var. <u>tritici</u>), and there was confusion as to the part played by each disease in the loss caused by the combination. GOULDEN and ELDERS in 1926 attempted to distinguish the losses caused by these two diseases by using 146 wheat varieties and determining the regression of yield on each disease. Because of a positive correlation between the two diseases they had difficulty in demonstrating the negative correlation between yield and leaf rust. The practical solution to this problem came with the introduction of varieties of wheat that were resistant to stem rust but susceptible to leaf rust, combined with the use of sulfur dusting to secure rust-free control plots. When this was done, especially by Canadian workers, the role of leaf rust in contributing to the damage caused by stem and leaf rusts combined was clearly brought out.

SALLANS' (1948) paper on losses from common root rot (<u>Helminthosporium</u> <u>sativum</u>) in wheat is an excellent illustration of the use of correlation and partial regressions to determine the individual and combined effects of root rot, pre-season rainfall, June-July rainfall, air temperature, and insect damage on wheat yields. It revealed that root rot was second only to June-July rainfall in causing yield variability, and that the yield-depressing effect of root rot, hitherto obscured by the other more obvious hazards, was actually much greater than had been suspected.

Another approach was used by CHESTER (1946a) in a study of losses caused by cotton wilt (<u>Fusarium</u> <u>oxysporum</u> f. <u>vasinfectum</u>) and potassium deficiency. This consisted of the analysis of a large body of data giving yields and wilt percentages of many varieties of cotton during a number of years, and comparing this with data from fertilizer tests. The study showed that when cotton suffers from wilt and potassium deficiency, up to 25% wilt the loss fractions from wilt and the deficiency are about equal, while above this wilt percentage, a greater part of the loss is due to wilt.

Still another approach was used by McNEW (1943j) in distinguishing the losses caused by anthracnose (Colletotrichum) and leaf blight (Septoria) in tomatoes. The fungicide, Fermate, controls anthracnose but does not control leaf blight, and spraying tests could therefore be used to measure the loss caused by anthracnose, though leaf blight was also present.

Numerous other examples might be cited, but these suffice to show that it is possible, by selection of suitable techniques, to break down complexes of loss factors into their several components and determine the part of each in the complex. In agriculture we deal more often than not with loss complexes, and the analysis of these deserves particular attention as one of the important problems in loss studies.

ECOLOGICAL INFLUENCES ON THE DISEASE INTENSITY-LOSS RATIO: -- If a given intensity of a disease at a given stage in development of the crop produces the same percentage of crop loss regardless of season or location, the problem of loss appraisal will be much simpler than if the loss percentage for a given disease intensity varies considerably from one year or location to another. It is to be expected that if loss measurement experiments are carried out in different locations and years some differences in disease intensity-loss ratios will result. Here we are concerned with the amount of variation in the ratios for different types of disease, the causes of this variation, and the question of whether the variation falls within the permissible range of error in loss-estimates or whether it is so great that loss measurements have only local or seasonal significance.

Disease Intensity-Loss Ratios In Different Years And Locations. -- There are many instances on record in which the loss caused by a given intensity of disease is relatively constant when it is measured in different years and locations. One might expect such constancy especially where the loss in an infected plant is total, and this appears to be the case with the cereal smuts. LEUKEL (1937), for example, in many measurements of loss caused by bunt in wheat, in different years and locations, concluded that "there was a high degree of correlation between the percentage of bunt in the crop from untreated seed and the percentage reduction in yield." Similarly SEMENIUK and ROSS (1942) found that the reduction in barley yield was directly proportionate and equal to the percent of loose smut (Ustilago spp.) with no significant differences in three widely separated locations.

With leaf diseases and injuries there also is frequently a rather constant relationship between degree of injury or involvement of the leaf and yield reduction, provided we compare equal amounts of injury at a definite stage in development of the crop. This is brought out in studies of corn leaf injuries conducted in different years in three States (Table 2). Rather uniform losses in different locations have been reported by McNEW (1943g) for tomato leaf blight (Septoria) and by J. D. MOORE (1946) for cherry leaf spot (Coccomyces). The results of numerous measurements of the loss caused by wheat leaf rust have been given graphically by CHESTER (1946b, Fig. 2) and show values that are well clustered about the averages for loss when wheat is defoliated at various developmental stages, despite the very different experimental conditions in the tests.

Table 2. Yield reductions due to corn leaf injuries in different locations and seasons.

Treatment	Relative yield of grain per acre (%): Illinois, 1 year (DUNGAN)	Iowa, 2 years (ELDREDGE)	Nebraska, 9 years (KIESSELBACH & LYNESS)
No treatment	100	100	100
All leaves removed at ligule	8	5	6
End halves of all leaves removed	57	67	77
All leaves shredded	84	57	76
All midribs broken near ligule	77	80	82
All leaf blades cut to midrib near ligule	80	90	84

A number of measurements of the loss from corn smut have been reported. On the whole these are in good agreement, though the tests were made by different investigators in different years and locations. The reduction in yield per stalk is given by HITCHCOCK and NORTON (1896) at 34.5%, IMMER and CHRISTENSEN (1928) 39% (average for all types of galls and not

corrected for the frequency of the different types of galls), JORGENSON (1929) 39% in selfed lines and 50% in F_1 crosses, IMMER and CHRISTENSEN (1931) 35% from galls of all types and 30% from all types of stalk galls, I. J. JOHNSON and CHRISTENSEN (1935) from 25% loss from single boils to 50% loss from multiple galls, and F. L. SMITH (1936) 31% loss. MENZIES and STANBERRY (1947) determined 22% loss from terminal boils in detasseled corn alone, so that their results are not exactly comparable with the others, and GARBER and HOOVER (1928) found a 25% loss from corn smut on the basis of barren stalks alone, but F. L. SMITH (1936) has shown that small boils and medium boils below the ear cause loss without barrenness, indicating why the results of GARBER and HOOVER are somewhat below those of the other workers.

For an entirely different type of disease, wood decay, R. M. BROWN (1934) has reported that in his studies of aspen there was a high correlation between volume of rot and various other tree characteristics but none between rot and site or soil type, and HEPTING (1941) found no significant differences in the amounts of cull from fire wounds of a given size, regardless of site or study area.

The Office of Cereal Crops and Diseases of the U. S. Department of Agriculture has published a table (KIRBY and ARCHER, 1927) to assist observers in estimating wheat stem rust losses, giving percent loss for each stage of rust intensity at different growth stages of the crop. Recommendation of use of such a table implies the belief that a given intensity of rust at a given growth stage is regularly followed by a relatively constant amount of loss, regardless of year, location, or other variables. CHESTER (1946b) has published a comparable table for losses from wheat leaf rust. This principle is opposed by RUSAKOV (1926), in Russia, who has contended that the relation of plant injury to crop loss varies so much from one geographical area to another that "for each region its own scale must be prepared from artificial inoculations of plots that are uniform for fertility and with uniform varieties of cereals".

GREANEY and his coworkers in Canada (1933b, 1941) have taken an intermediate position. For 9 years at Winnipeg, by means of sulfur-dusting experiments, they measured the loss from stem rust in Marquis wheat. Finding that the regression of yield on percent rust was linear, they could determine the percent loss in yield due to each 10% of rust. These values, for each year, were used in calculating the total loss from rust in Manitoba and Saskatchewan, and similar work was done with oats stem rust. Each 10% of rust, in the various years, produced 9.7, 7.4, 6.9, 8.2, 7.9, 3.1, 6.7, 7.3, and 9.2% yield reduction. These values do not show excessive variation from year to year. One cause of such variation as does occur was the fact that during some years leaf rust damage was present, to complicate stem rust-loss relationships. While GREANEY et al. have recognized certain sources of error, they consider that the method adds precision to loss estimation, and their belief in the validity of a wide application of an experimentally derived disease intensity-loss ratio is seen in the fact that for each year the ratio obtained on one wheat variety at one location was applied to an area which regularly produces 200, 000,000 bushels of wheat.

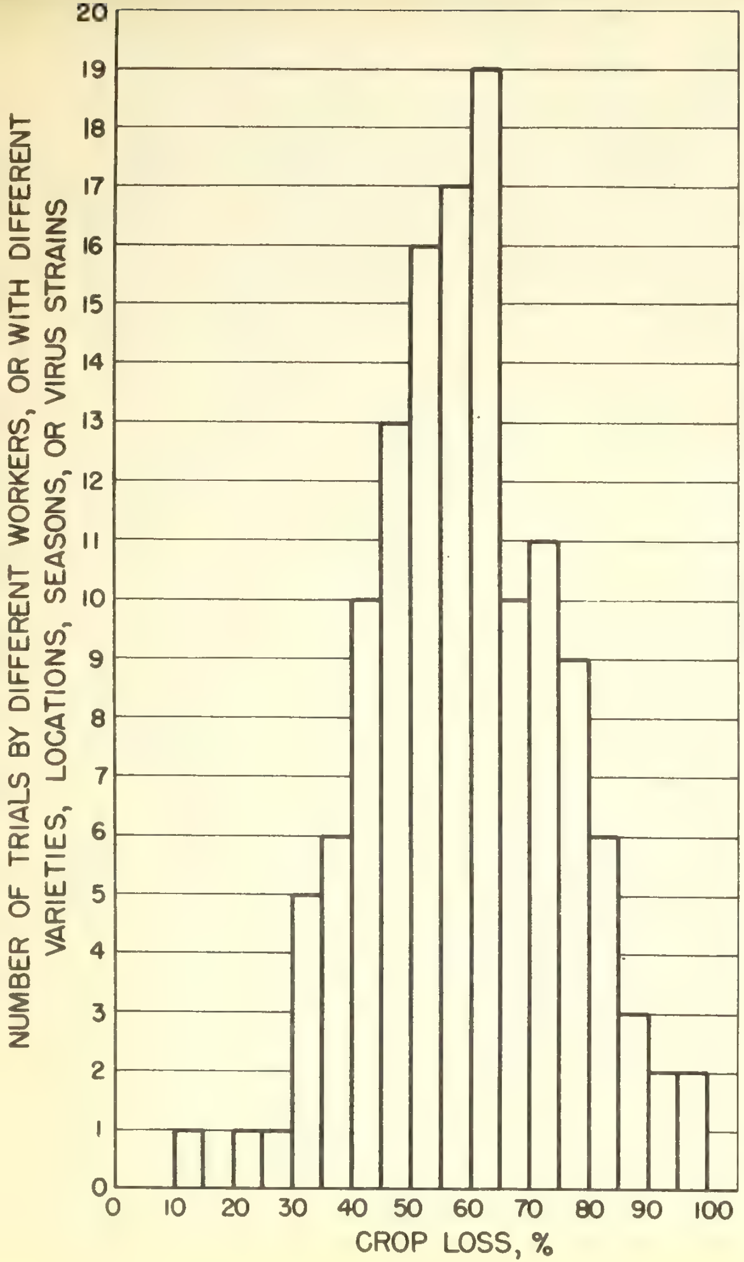
The case of potato leafroll is one for which we have many loss data from different workers, potato varieties, locations, and seasons. The measured amounts of loss from 100% leafroll in 132 tests are shown graphically in Figure 3. These are based on 29 published accounts.

Analysis of these data by J. H. McLAUGHLIN shows that the mean for all measurements is 59.59% loss with a standard error of $\pm$ 1.41, which implies that for similar bodies of data the mean loss is expected to be between 58.18 and 61.00% in 2 out of 3 cases.

There are many factors responsible for the range of loss percentages in the case of potato leafroll. A universal loss constant in the vicinity of 60% might not be applicable in isolated instances when the true loss percentages are far higher or lower than this. Yet, in loss appraisal we are more interested in the volume of loss over large areas, embracing many years, environments, and crop varieties, than in exact determination of loss in single fields. If the figure 60% be taken as a universal loss constant in this case, we can confidently place the volume of loss caused by this disease in its proper order among potato diseases, and we can justify calculations of the magnitude of the loss on a broad scale by the high statistical probability that when losses in many locations, seasons, and crop varieties are considered together, the mean loss will not be far from this figure.

This case brings out the important principle that although there may be considerable discrepancy between two isolated loss measurements of a given disease under different environments, that is not a valid deterrent to efforts at securing universal loss constants, since a large body of loss data, such as we have for potato leafroll, shows a good normal distribution around a mean, which may be used in the same manner and with the same confidence as the agricultural economist uses means of crop yields, with full appreciation that yields in individual fields may be far higher or lower than the means.

Effects Of Climatic Factors On Disease Intensity-Loss Ratios. -- Differences in disease



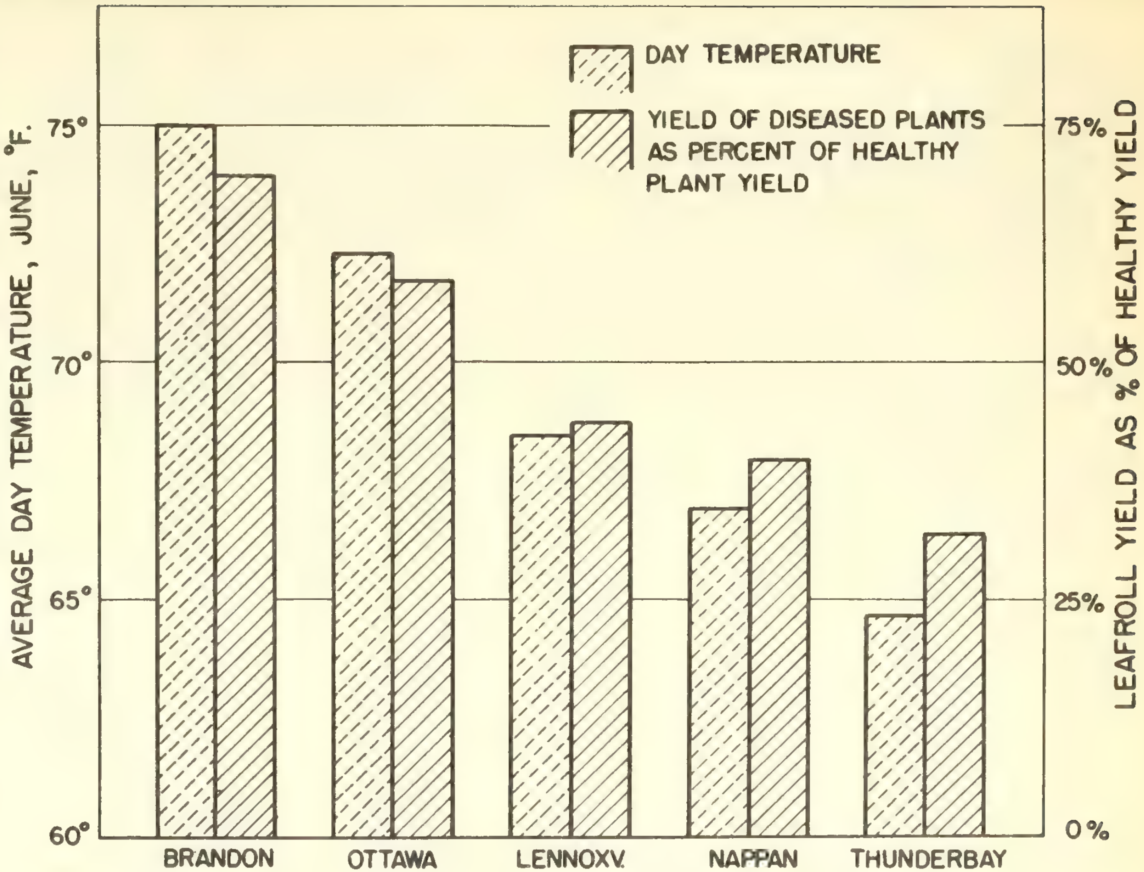


Figure 4 (above). Relation between temperature and percent crop reduction caused by potato leafroll at 5 Canadian stations. (Arranged from P. A. MURPHY, 1921.)

Figure 3 (left). Distribution of 132 recorded measurements of loss from 100 percent potato leafroll, based on 29 published accounts.

intensity-loss ratios from one location or season to another, where they occur, are due to differences in climatic, edaphic, biotic, and cultural factors, alone or in combination. In this and the two following sections an attempt is made to distinguish the effects of these factors.

A number of investigators have stated that the amount of loss caused by a given concentration of disease may vary with the water supply. In the case of Texas root rot in cotton, EZEKIEL and TAUBENHAUS (1934) found that under irrigation the intensity-loss factor is only about 1/2 that for cotton grown under natural moisture conditions. However, under the varying rainfall of different seasons and locations, after a 12-year study they concluded that the "loss-estimation ratio" (a factor which is multiplied by the percent of plants killed at the time of the first picking to give loss percent) varied only from .85 to .95 with rainfall and that an average ratio of .9 was sufficiently accurate for use in calculating the annual loss from root rot in Texas.

In very dry summers, after there has been adequate rainfall earlier in the season, some crop scientists and growers feel that there is an advantage, or at least little harm, in some degree of defoliation. If this is true, diseases which attack leaves might be expected to cause greater relative loss during moist seasons than in dryer ones. LUDWIG'S data on cotton (1927) show that defoliation at any time is harmful, but that the greatest percent of crop reduction from defoliation occurs in the wetter environments. He defoliated cotton at two dates in dry, moderately irrigated, and very wet plots, and when the percent of loss caused by defoliation is calculated from his data it is seen that with early defoliation the loss of seed cotton was 26.0, 51.2, and 60.6% in passing from the dryest to the wettest plots. With late defoliation the corresponding figures were 0.8, 6.1, and 10.0% loss, and similarly, greater loss ratios with increasing moisture are seen in his data on number of bolls, weight of seed, and weight of lint.

This is an isolated instance and the existing data relating moisture to disease intensity-loss ratios are far too few to permit any generalizations. For the present we must proceed from one crop and disease to the next, entirely on an empirical basis, with the expectation that as data of this sort accumulate we will be able either to develop certain general principles governing the moisture-loss relationship or, if not, we can at least determine this relationship for important individual cases, as the Texas workers have done for cotton root rot. We may expect to find much variation in these relationships, depending on the physiology of the crop, the nature of the disease, and the organs harvested, As an example, MOLOTKOVSKY (1945) in Russia holds that when potato growth is checked by midsummer heat and drought, yields are <u>increased</u> by mowing the vines. This is not unexpected, since under these conditions respiration and the consumption of carbohydrates may exceed photosynthesis and food storage.

In some cases differences in temperature may be expected to produce important differences in disease intensity-loss ratios. Figure 4 shows how the percentage of crop loss increases as the temperature falls in the case of potato leafroll.

P. A. MURPHY (1921) observed a comparable, though less striking relationship between increase in temperature and decrease in loss percentage in the case of potato mosaic. It is generally true of virus diseases that disease symptoms, which include yield reduction, are most marked at low temperatures, and that they diminish or even become entirely masked at high temperatures. This would seem to explain higher disease intensity-loss ratios from virus diseases in general when loss measurements are made in cool localities and seasons.

In cases of disease which destroy plants early in the season, the loss is somewhat compensated for by the growth advantage in adjacent plants, a subject which is considered in detail in Chapter X. In the present connection, however, it should be mentioned that LIVERMORE (1927) has reported that this compensating effect is very much influenced by soil and climate.

<u>Effects Of Edaphic Factors And Crop Vigor On Disease Intensity-Loss Ratios</u>. -- The data relating soil properties to disease intensity-loss ratios are also scarce, although a number of investigators have suggested that the soil may influence these ratios. GRAM (1923), in his study of the effect of environment on potato leafroll, furnished data which indicate that the losses for a given intensity of disease were much more uniform when 12 Danish locations were compared during the same season than when different seasons in the same location were compared. Similarly, McNEW (1943a) has presented data which show that in one variety of peas the loss percentages in yields which are controllable by seed treatment varied only in a minor fashion (31.5, 40.0, 36.7, 30.8%) in experiments involving essentially the same disease intensity in variously fertilized and unfertilized soil. In a second variety, however, the loss was 22% in unfertilized soil but only 8% in fertilized soil. In the case of sugar beet yellows, HULL and WATSON (1947) found that although soil fertilization greatly affected yields, it had little influence on the percentage yield reduction due to the disease.

In contrast to these results there are several reports which indicate that crops under poor growing conditions have higher disease intensity-loss ratios than more vigorous crops. With mosaic of greenhouse tomatoes, HEUBERGER and NORTON (1933). have pointed out that uniform

infection by this disease produced significantly greater loss when the plants were growing under somewhat unfavorable conditions in a bed, than under better conditions on the greenhouse bench. SCHULTZ, BONDE, and RALEIGH (1934) also have indicated that given intensities of virus diseases have a less depressing effect on potato yields under the ideal growing conditions of Aroostook County, Maine, than under the less favorable conditions of Long Island, and LECLERG et al. (1944) made a similar comparison between lower losses from spindle tuber and leafroll of potato in Maine and higher losses in Louisiana.

In apparent contradiction to these results, HEUSER and BOEKHOLT (in LUBISHCHEV, 1940) have advanced the supposition that under good growing conditions cereal leaves are fully functional and that removal of part of them has a more serious effect than comparable removal of the supposedly less efficient leaves of poorly growing plants. LUBISCHEV asserts that this view is not compatible with the data from rye defoliation experiments, and SWANSON (1941) has brought out clearly the fact that in sorghum the leaves are much more efficient in producing grain during seasons of limited rainfall than in moist seasons when the plants grow more vigorously.

Effects Of Biotic And Cultural Factors On Disease Intensity-Loss Ratios. -- We are again faced with non-uniformity in the scanty data relating disease intensity-loss ratios to biotic and cultural factors. In the case of sugar beet yellows, the time of sowing has little effect on the losses, according to WATSON et al. (1946), although T. W. WHITEHEAD (1924) advances different cultural practices as a cause of variation in measurements of loss from potato leafroll.

The percentages of loss in potato from comparable amounts of late blight are greater if the crop is simultaneously affected with other diseases, in the experience of BEAUMONT and LARGE (1944), while McNEW (1943f) measured very similar loss percentages from tomato leaf blight (27.8, 23.8%), whether or not the crop was also protected with an insecticide.

In the case of the potato viruses some doubt has been cast on the validity of most or all of the early studies of loss, since the X-virus has been almost universally present in many commercial potato varieties, and the losses reported as due to leafroll, mosaic, or other viruses have actually been based on comparisons between leafroll, mosaic, etc. plus X-virus, with supposedly healthy checks containing X-virus.

Antibiotic organisms may also cause variations in the loss constants. This is well illustrated in a study of cereal root rot by GREANEY and MACHACEK (1935). They observed that when the harmless saprophyte, Cephalothecium roseum, was introduced into infection experiments with the root rot fungus, Helminthosporium sativum, the aggressiveness of the latter was decreased and there was less injury to wheat seedlings as shown by their greater dry weights.

VARIETAL INFLUENCES ON THE DISEASE INTENSITY-LOSS RATIO: -- Does the disease intensity-loss ratio vary in an important degree from one crop variety to another? If so, what are the reasons for this variation, and how may we circumvent the difficulty in loss appraisal practice?

Fifty sources of data on this question have been consulted, and these show a wide range of situations, varying from cases in which practically no difference in loss constants is seen in different crop varieties to the other extreme in which a given disease, at a given intensity and with other factors comparable, may cause yield reductions ranging from 0% to 71% (sugar cane red rot, Colletotrichum falcatum) or from 14% to 95% (potato leafroll).

Only minor differences in loss constants from one variety to another, under comparable conditions, have been reported for such varied diseases as tomato streak (L. K. JONES and BURNETT, 1935), butt rot and top rot in oak species (HEPTING et al., 1940, 1941), damping-off in castor beans (STEVENSON, 1947), defoliation of apple and pear varieties (MAGNESS, OVERLEY, and LUCE, 1929, 1931), citrus psorosis (TIDD, 1944), mild mosaic of potato (BONDE et al., 1943) potato X-virus (SMITH and MARKHAM, 1945), and sugar beet yellows (HULL and WATSON, 1947).

Minor to considerable differences in loss constants of different potato varieties have been found in the cases of spindle tuber (SCHULTZ and FOLSOM, 1923; YOUNG and MORRIS, 1930, McKAY and DYKSTRA, 1932; BONDE et al., 1943), "mosaic" (SCHULTZ and FOLSOM, 1921; WHITEHEAD and CURRIE, 1931), and curly dwarf (WHIPPLE, 1919).

Very marked differences in loss constants between varieties are reported for cowpea mosaic, (5.7-52.0%, Anon., 1942), sugar cane red rot (0.0-71.0%, EDGERTON et al., 1937), and soybean defoliation (17.0-51.0%, etc., GIBSON et al., 1943).

In the case of sugar cane mosaic a wide range in loss constants from one variety to another has been reported by BRANDES (1919), LEE (1929), EDGERTON et al. (1937), and M. T. COOK (1947), although in Brazil FREISE (1930) has stated that the decrease in sucrose caused by cane mosaic is independent of variety.

Potato leafroll is a unique example of a disease for which we have a wealth of data on loss constants based on some 30 publications. K. M. SMITH (1946?) has classified 22 British potato varieties in three groups according to the percentage loss caused by leafroll, with 80% or more loss in 7 varieties, 50 to 80% loss in 11 varieties, and less than 50% loss in 4 varieties. Inconsiderable varietal differences in the leafroll loss constants, under comparable conditions, have been reported by SCHULTZ and FOLSOM (1921), TUTHILL and DECKER (1941), BONDE et al. (1943), and LECLERG et al. (1944, 1946). Somewhat greater differences were found by MURPHY (1923) and BONDE and SCHULTZ (1940), while a very wide range of leafroll loss constants in different varieties, in accordance with K. M. SMITH'S grouping mentioned above, is given by WHITEHEAD and CURRIE (1931) who report losses from 100% leafroll of 14.0 to 95.0% in 1924 and 26.0 to 97.6% in 1929.

In comparing loss constants of different crop varieties we distinguish two situations. First, there is the comparison between disease-resistant and susceptible varieties where resistance is expressed as a reduction in intensity of disease (percentage of plants attacked or tissues involved). A valid comparison may only be made between equal intensities of disease. In this case, if resistant and susceptible varieties are growing side-by-side, subject to the same inoculum potential, there will be a marked difference in percentage of crop loss because the varieties are diseased to different extents, and not because of the ability of one variety to suffer less than another when infected to the same extent. In this category belong many of the variety comparisons with respect to rusts, smuts, root knot, and the wilt-resistant varieties in which an occasional plant succumbs. This situation presents no difficulty in crop loss appraisal provided our loss conversion factors are based on disease intensity.

The second, and more difficult situation is the case where resistance to crop loss is due to differences in the nature of reaction of different varieties when diseased to the same extent. In this case resistant varieties express their resistance by tolerance of disease, rather than relative freedom from disease. If this occurs to an important degree we cannot have universal loss constants, since a given intensity of disease will produce much less loss in the tolerant varieties than in others.

Tolerance of disease may take various forms. We see it in the more drought-resistant cereals, which can withstand the excessive loss of water caused by rust and powdery mildew infections and produce fairly good yields despite this handicap. A good example is the reaction of two varieties of wheat in the experiments of SALMON and LAUDE (1932), which were unlike the other 22 varieties tested in that one produced a high yield though heavily infested with leaf rust, while the other yielded well in spite of a high intensity of Septoria leaf blotch.

Another form of tolerance is related to the vegetative cycle of the variety. This will be considered more fully in a later section, and here it is only necessary to point out that if two varieties suffer the same intensity of disease at a given time, one may sustain less loss if the time of appraisal is closer to its time of crop maturity than in the other, later-maturing variety.

When a disease kills some plants outright, leaving adjacent plants unharmed, the adjacent plants are favored by the greater growth space provided, and to some extent will compensate for the loss of the missing plants. In corn (KIESSELBACH, 1922; BROWN and GARRISON, 1923), and doubtless in other crops, this compensating ability differs among varieties and a variety in which this characteristic is highly expressed will suffer less loss from a given percentage of disease than other varieties. This represents another form of tolerance.

Very clear-cut cases of tolerance are seen in those diseases where intensity is total, where the plant is either entirely (systemically) infected or not at all. This is very well illustrated in the virus diseases, and particularly those that are established in vegetatively propagated plants, where time of infection is also a constant. While the physiological explanation is not forthcoming, it seems clear that when two crop varieties are infected with the same virus strain one may show more marked symptoms of injury than the other, and this greater or less tolerance may underlie some, though not all, of the differences in loss constants seen in virus diseases.

In other cases of virus disease, such as sugar cane mosaic, some plants have the ability to recover from the infection, which represents another varietal characteristic that may cause variability in loss constants (EDGERTON et al., 1937).

We have seen that with virus diseases, particularly those of potato and sugar cane, some investigators have found fairly high uniformity in the loss constants for a given disease in different host varieties, while other workers have reported great differences in these constants. These discrepancies may be due to several causes, including varietal tolerance to disease, the presence of more than one virus in experimental plants, inaccurate diagnosis of virus diseases, and differences in the virulence of the virus strains concerned in different experiments or different host varieties.

EFFECT OF PATHOGENIC STRAIN ON THE DISEASE INTENSITY-LOSS RATIO: -- Potato and sugar cane viruses are perpetuated for indefinite periods in the process of vegetative propagation. The loss from such a virus as leafroll in a given potato variety is a function both of the varietal response and the virulence of the particular strain of leafroll virus that happens to be present in the variety. When two leafroll-infected potato varieties are compared, differences in the loss constants may be due to varietal differences in tolerance of the virus, differences in aggressiveness of two virus strains, or a combination of the two. When, in addition, the diseased varieties and "healthy" checks are found also to contain the ubiquitous X-virus, or even different strains of the X-virus in the several varieties and checks, we can see that there is ample opportunity for variation in loss constants.

The X-virus does exist in the form of many strains, and BALD (1943b) has shown, in a highly significant study, that the different strains cause losses ranging from 12% to 45%, the loss percentage being characteristic of the strain and of the degree of symptom expression. The effect of virus strains in producing different loss ratios has been recognized by some of the investigators who have published data on this problem and who have referred to their viruses by such terms as "severe leafroll", "mild leafroll", etc.

It has also been recognized by those who have worked with sugar cane mosaic that observed differences in losses have been due not only to response of the cane varieties but also to the presence of cane mosaic strains of different virulence (EDGERTON et al., 1937; M. T. COOK, 1947).

CONCLUSIONS ON THE FACTORS AFFECTING DISEASE INTENSITY-LOSS RATIOS: -- The question of the extent to which intensity-loss ratios for given diseases vary under the influence of different environmental, varietal, and pathologic factors cannot be answered by any broad generalizations, on the basis of the limited data so far available. For some diseases, the losses from which have been rather thoroughly studied, given intensities of disease produce similar percentages of loss quite consistently, despite the fact that the loss measurements have been made under widely varying conditions.

For purposes of appraising plant disease losses we need to have standard disease intensity-loss constants wherever it can be shown that the variation of these constants from one environment, variety, or pathogenic strain to another is not greater than the permissible range of appraisal error. It is becoming evident that with some diseases we can have and use such universal constants (cereal rusts, smuts, certain virus diseases, etc.). With some other diseases it is likely that the disease intensity-loss ratios will vary so greatly under different conditions that a universal loss constant cannot be used. In these cases there are several possible procedures: to determine the constant in one location for each season and then apply it to a broad area, as GREANEY did for wheat and oat rust; to determine the average constants for each of several large areas and use these annually as regional constants; or a combination of the two, as would be the case if the intensity-loss relationship for a given disease in a single State were to be determined for each season and then applied to estimation of the loss from the disease in that State and season only. The latter is not too laborious for routine practice. The measurement of the loss constant is obtained through a relatively simple field experiment which would require only a small fraction of the time of an investigator who is chiefly interested in one or a few diseases of a single crop within a limited area, in conformity to present-day professional specializations.

There is no indication, from the data thus far available, that differences in the disease-tolerance of varieties of a crop will lead to widespread difficulty in the derivation and use of loss constants. In various types of diseases it is apparent that the disease intensity-loss ratios for numerous varieties of a given crop are sufficiently uniform for our purpose, and that there is no necessity for deriving individual loss constants for each variety. When we occasionally encounter a case, such as that of potato leafroll, in which there is a wide range of degrees of loss depending on variety, the practical problem of loss appraisal can be solved by the simple device which K. M. SMITH has used, of classifying varieties into a small number of groups, each with its uniform group loss constant within a practically useful range of error.

The range of error of the loss constant will determine, among other factors, the range of accuracy of the loss estimate. For some diseases in which the intensity-loss ratios are quite variable we may be forced to accept loss estimates which have fairly wide ranges of error, but which may still have some value in determining, even roughly, the magnitude of loss.

It would be folly to assume that for each disease there can be determined a loss constant which will be independent of crop environment to even a practical degree. It would be equally extravagent to reject all use of loss constants because losses from given intensities of some dis-

eases are highly variable from one environment to another. The loss constants are a kit of tools, some of which are sharp, others dull, while still others are lacking, but such a kit is far preferable to no kit at all.

Some of the lacking tools can be supplied and some of the dull ones can be sharpened as our source data on crop loss measurements increase. The potential value of loss constants is great enough to warrant concerted and industrious efforts to determine them, for many diseases in many environments and varieties.

RELATION OF DISEASE INTENSITY TO LOSS IN CONNECTION WITH THE VEGETATIVE STAGE IN WHICH THE CROP IS ATTACKED: -- It is patent to every plant pathologist that the effect of a given intensity of disease will vary greatly according to the stage of development of the crop at the time this disease intensity is reached. Considering this fact it is curious that in many reports of plant disease occurrence the crop stage is not indicated, and as a result the data may have little comparative value. The data of a disease occurrence, which is more often given, is not sufficient, since plants pass through their several growth stages at entirely different times according to location and season.

Experiments on artificial defoliation of plants to simulate the effects of disease, insect injuries, or hail damage, which are discussed at length in Chapter IX, have shown a similar trend in all the crops studied, -- corn, onions, barley, oats, flax, sorghum, wheat, and soybeans. In all cases, the loss of leaves in midseason causes the greatest reduction in yields, while if the defoliation is progressively earlier or later in the course of plant development, the loss produced is progressively less, until it becomes negligible in plants that are defoliated in the early seedling stage or at submaturity. This effect is proportionate to the fraction of leaves removed but similar in character regardless of the degree of defoliation. When disease attack is on the organs which are to be harvested, a different relationship holds; here the proportionality between attack and loss frequently becomes greater with the approach of harvest time.

The literature abounds in reports of a positive correlation between time from disease attack to harvest and amount of loss produced, from midseason onward, as is well seen in the leaf diseases of potato and tomato, the root rots of cotton and cereals, and the cereal rusts. There have been occasional detailed studies of this phenomenon, such as that of EZEKIEL and TAUBENHAUS (1934) who determined the reduction in yield from cotton plants that were killed by Texas root rot at weekly intervals from June to September, the loss grading from total to none during this period.

The tables for estimating losses from wheat stem rust (KIRBY and ARCHER, 1927) and leaf rust (CHESTER, 1946b) are devices based on the tenable assumption that loss from rust becomes progressively less with increasing delay in reaching any given intensity. This assumption is borne out, not only by common observation, but also by such experiments as those of MAINS (1927, 1930) and JOHNSTON (1931) with wheat leaf rust, or of BEVER (1937) with wheat and barley stripe rust (Puccinia glumarum).

As early as 1915 GASSNER was using and recommending a method of appraising cereal rusts in which both rust intensity and plant growth stage were scored, and this method was adopted by G. J. FISCHER (1929) and a few others, but has never been commonly practiced. In 1936, GASSNER and STRAIB proposed the concept of "injury coefficient", an expression of the percentage decrease in yield per week from attack of rust of a given strength. They found, for example, that for moderate stripe rust the injury coefficient was approximately 3% and for severe stripe rust 5%. Granting that these coefficients would be likely to vary with location and season, they do represent a useful attempt to bring the time factor into the orbit of rust appraisal in a workable fashion.

Consideration of the vegetative stage of the crop has also been emphasized in Russia (RUSAKOV, 1927, 1929b; TOUMARINSON, 1934), where it is recommended that cereal rust appraisals be made several times during the growing season so that the data will show the rust intensity for each variety in comparable growth stages, not merely on one calendar date, when some varieties may be barely headed while others are well advanced toward maturity. RUSAKOV has presented data showing one order of rust intensity for wheat varieties according to appraisals on a single date, with a different, and more correct, order when each variety was appraised in the same (heading) stage.

For virus diseases, numerous investigators agree that the amount of loss is directly proportionate to the earliness in the life of the plant when it becomes infected. This has been found true of tobacco mosaic (VALLEAU and JOHNSON, 1927; McMURTREY, 1928, 1929; WOLF and MOSS, 1933; JOHNSON and VALLEAU, 1941), tomato mosaic (NORTON, 1914; HEUBERGER and NORTON, 1933), current season infection of potato leafroll (L. K. JONES, 1944), sugar beet yellows (WATSON et al., 1946), and bean mosaic (FAJARDO, 1930). In the last case the loss may vary

from none to total depending on the growth stage at which the plants contract infection, while for tobacco mosaic McMURTREY (1929) has measured losses in acre value that ranged from 57% loss in plants inoculated at transplanting time to 13% loss from inoculation two months later, at topping time.

In forest pathology it is elementary that the amount of loss from wood decay varies directly with the age of the tree at the time of infection, and with other perennial crops the loss must frequently be considered as a function of the length of time, in years, during which the plant has been subject to disease. With the systemic virus diseases of fruit and other trees the loss in any year depends on the number of years since infection, and even with local, annual diseases the loss must be reckoned in terms of the number of years of attack preceding the present year, as shown for cherry yellows by J. D. MOORE and KEITT (1946).

These examples clearly indicate the importance of considering growth stage of the plant in disease appraisal if results of different observations are to be comparable and if we are to have a logical basis for converting disease intensity into disease loss. This principle has a broader application in pathology, since, as BEAUMONT and LARGE (1944) have indicated, in disease control experiments disease intensities must be recorded in terms of the stage of plant development if the control data are to be fully useful.

THE TEMPO OF DISEASE DEVELOPMENT: -- The outcome of a horse race is determined not so much by the position of the horses at any given moment as by the speed at which they are running. So, too, with plant diseases; a single inspection of disease may give very little indication of the dynamics of disease development. Just as an experienced seaman can determine the course and speed of a distant ship by signs that are meaningless to the landlubber, so the phytopathologist can learn to recognize the evidences that a plant disease is accelerating, static, or decelerating in intensity. It is important that we give attention to the dynamics or tempo of disease development, since this increases our ability to foresee future loss, sometimes early enough to permit the intervention of loss-preventive measures.

Study And Recording Of Disease Tempo. -- The tempo of disease is studied by the simple device of appraising disease intensity at regular intervals during the growing season, using a method of scoring disease intensity that will permit a valid comparison of the successive readings, plotting the data in such a form as will graphically illustrate the tempo, and correlating the trends with the ecological and pathological factors which determine the dynamics of disease.

It may be necessary to make thorough and time-consuming searches to reveal the early steps in disease development. In studying the tempo of cereal rusts, for example, the work should begin long before rust becomes obvious, to obtain numerical values for the important early generations of rust increase. This may require examination of as many as 1000 to 5000 leaves or culms, selected at random. The data should include not only records of the amounts of disease present, but also information on the character of the infections, since this gives useful information on the energy of disease increase. It is important to note, in addition to the number of lesions, their type, -- whether they are old and more or less inactive or whether they bear evidence of having recently developed with more incipient lesions in the process of formation.

Disease frequently increases at a geometrical rate as time advances by arithmetical steps. Therefore a logical and useful way of plotting disease tempo data is on semi-logarithmic coordinates with disease intensity on a logarithmic ordinate and time on an arithmetical abscissa, as in Figure 5. If disease intensity is expressed as percent, the probability scale (logarithmic in each direction from the 50% point, as in Fig. 3 in HORSFALL, 1945, reproduced here in Figure 14, page 248) is preferable.

BARRATT (1945) suggests the following procedure in studying the tempo of disease development as an aid in evaluating fungicides or genetic differences in plants. Disease readings, using a graded scale of disease intensity, are taken at regular intervals during the growing season. The average disease at each reading is graphed on arithmetic-probability coordinates to give the seasonal disease trend. From the trend curve, which often approximates a straight line, the number of days necessary for a variable to reach any given level of disease can be ascertained by interpolation. As a variation (HORSFALL, 1945) the time scale (absicca) may be logarithmic, with time considered as a dosage factor. The purpose of the probability and logarithmic coordinates is to use scales which are most characteristic of the biological phenomena being studied, disease increase commonly being at a logarithmic rate. These are more likely to show straight-line relationships between disease and time, permitting extrapolation, which is not effectively done with the customarliy sigmoid curves that result when disease tempo is plotted on an ordinary double-arithmetic grid.

The following method of recording disease tempo has been used by BALD (1937) in work with the spotted wilt virus disease of tomatoes. The "infection rate" is a quantity independent of the

numbers of plants already diseased; it gives the number diseased relative to the number remaining healthy. It is calculated by subtracting the natural logarithm of the number at the beginning of the period, and dividing by the number of days or weeks to give daily or weekly infection rates. Major changes in the infection rate are associated with important factors influencing infection, such as weather or availability of vectors.

Principles Seen In Studies Of Disease Tempo. -- Studies of the tempo of development of different diseases bring out certain principles. One of these has been suggested, namely that while the amount of new infection during any period depends on the amount of infection at the beginning of the period, the rate of infection is independent of the number of plants already diseased. Many disease organisms increase from minor to destructive amount by a series of generations of increase. The increase factor, whether 10-, 100-, or 1000-fold per generation, is a value that is peculiar to the biology of the pathogen and is independent of the amount of disease already present until it becomes limited by a lack of new host tissues to attack. In such a case the tempo of the disease may be expressed as the rapidity with which these generations succeed one another.

CHESTER'S (1946a) analysis of the tempo of cotton wilt (Fusarium), illustrated in Figure 5, shows that the tempo of wilt development for a large number of cotton varieties in one location and season is quite constant, regardless of their resistance or susceptibility to wilt. In contrast, the tempo of this disease for all varieties in one location and season differs markedly from that of a comparable group of varieties in a different season. In the same paper are given tempo curves which indicate that although various fertilizer treatments raise or lower the level of wilt infection of one variety of cotton in a given location and season, there is no marked change in the tempo. This analysis shows that the tempo of development for this soilborne disease appears to be a function of the seasonal weather, unrelated to varietal disease reaction or to soil fertility, and that from one season to another the tempo of disease development varies widely but uniformly for all varieties in one soil or for one variety in all soils.

Airborne diseases may also display this principle, as brought out for potato late blight in Figure 6. Here the differences in tempo for one location in three seasons are much greater than those for four locations in one season.

In dealing with perennial crops, the tempo of diseases which reduce the stand may be measured in years. An excellent example is bacterial wilt (Corynebacterium insidiosum) of alfalfa, a soilborne disease which usually does not become apparent until alfalfa stands are about two years old, and then progressively destroys the plants through succeeding years until the stands become unprofitable.

Data on the tempo of alfalfa wilt have been supplied by SALMON (1930), GRABER and JONES (1935), WIANT and STARR (1936), and WEIHING et al. (1938). Figure 7, based on data in the latter paper, is typical of the results obtained by all these workers. It shows the steady march of the disease, with each semiannual stand count showing roughly 75% as many plants as in the preceding count.

If the plant disease appraiser can regard any pathological situation not as a static, isolated event but as a momentary stage in a dynamic process, or as a single frame in a moving picture, he can obtain a much more accurate loss appraisal, because he visualizes not only present indications of loss accomplished, but also the inevitable loss of the future as the disease proceeds.

Our data on disease tempo are far too few but they show how tempo studies can contribute to loss forecasting. From such information as that given in Figure 7, one can anticipate, with sufficient accuracy to be useful, the profitable life of wilt-infested alfalfa stands and the annual decrease in their value. In England, WATSON, WATSON, and HULL (1946) have studied the tempo of the sugar beet yellows disease, have found a linear relation between time and disease loss, and, as a result, have developed a method for forecasting yields which is helpful in planning beet sugar factory operations. The forecasting of future forest decay, which has become a well-founded practice, is an application of the same principle, since annual decay increment is just another way of expressing the idea of tempo in the case of wood decay.

But the utility of disease tempo studies is not limited to loss forecasting. BARRATT (1945) has shown the value of having a mathematical expression of the "intraseasonal advance of disease" (i.e., tempo) in evaluating fungicide performance and differences in the reactions of crop varieties toward disease. That tempo studies may shed light on the nature of disease resistance in crop varieties is brought out by a comparison of tempo in cotton wilt and tomato wilt. In the former case (Fig. 5) the tempo curves for resistant and susceptible cotton varieties are approximately parallel, indicating here that the rate of increase of disease is independent of varietal resistance although the amount of disease is much less in the resistant varieties. In contrast, WELLMAN'S data (1939) for tomato wilt (Fusarium oxysporum f. lycopersici) (Fig. 8) show a rapid tempo of disease increase for a susceptible variety, a slower tempo for a partly resistant

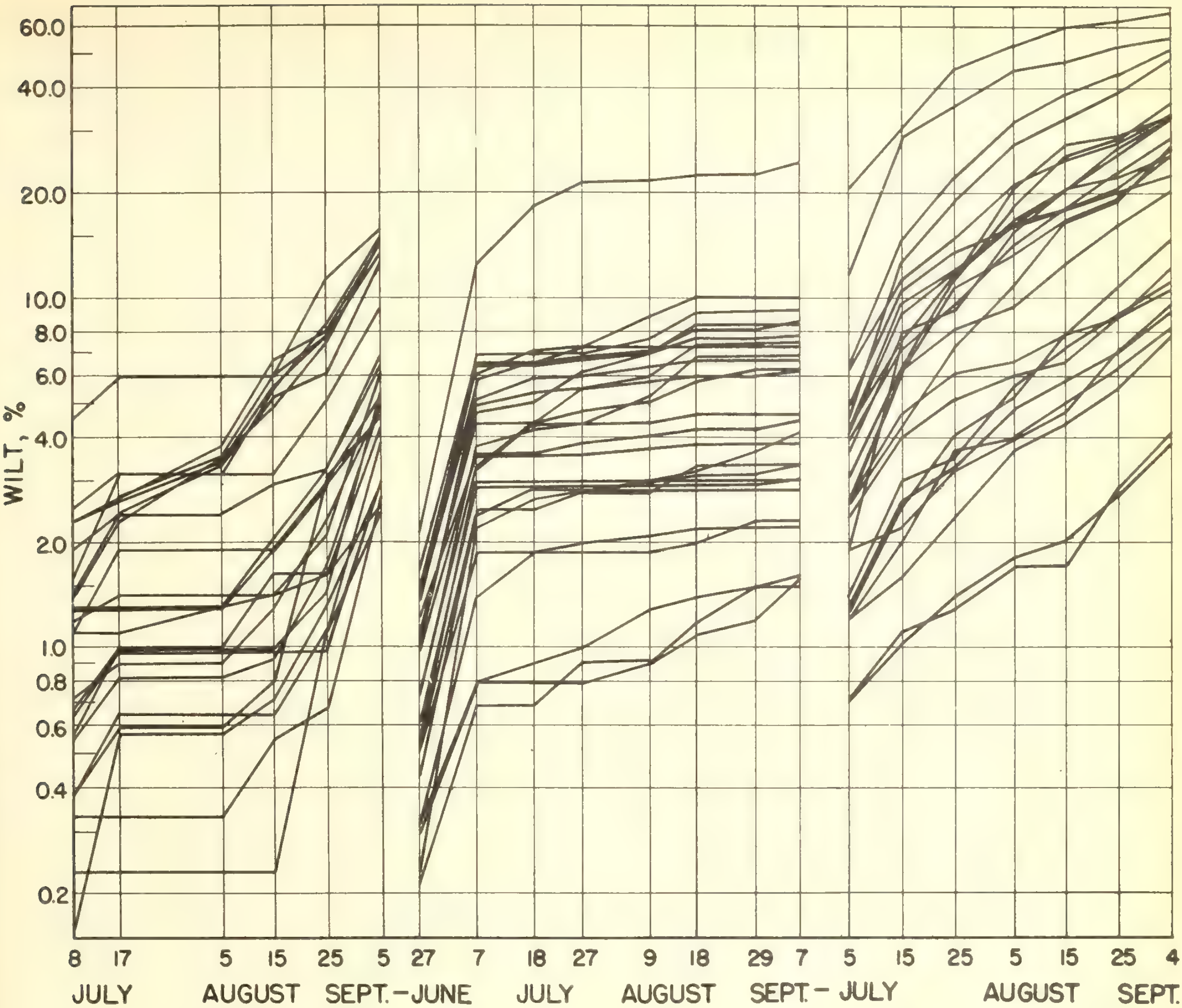


Figure 5. Tempo of cotton wilt development as indicated by tests of 26 varieties in each of 3 seasons at the Cotton Branch Experiment Station, Arkansas. (After CHESTER, 1946a.)

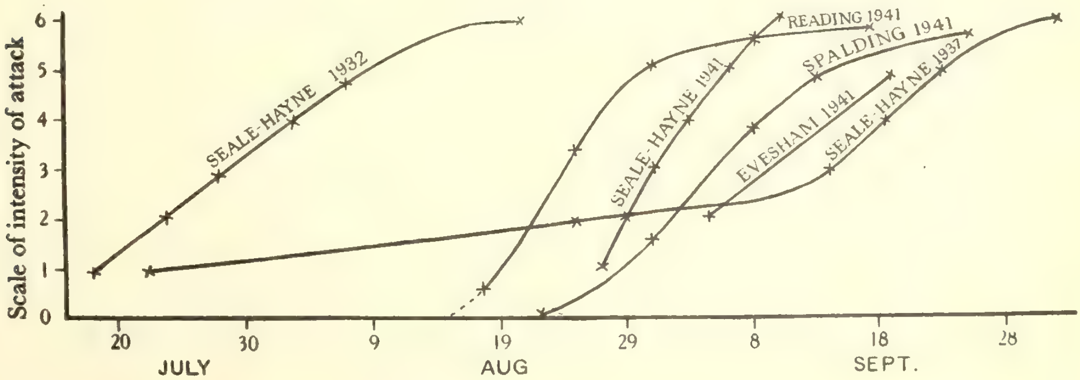


Figure 6. Tempo of potato late blight during 3 seasons at one location and one season at four locations. (After W. C. MOORE, 1943.)

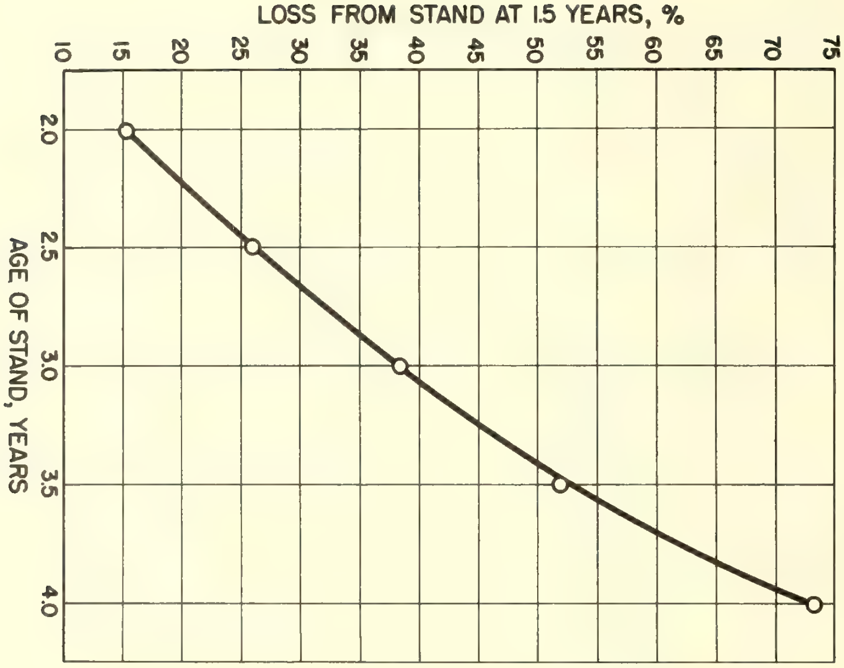


Figure 7. Tempo of stand loss from alfalfa wilt. Averages of 5 tests with average of 7 strains of alfalfa in each test. (From data of WEIHING et al., 1938)

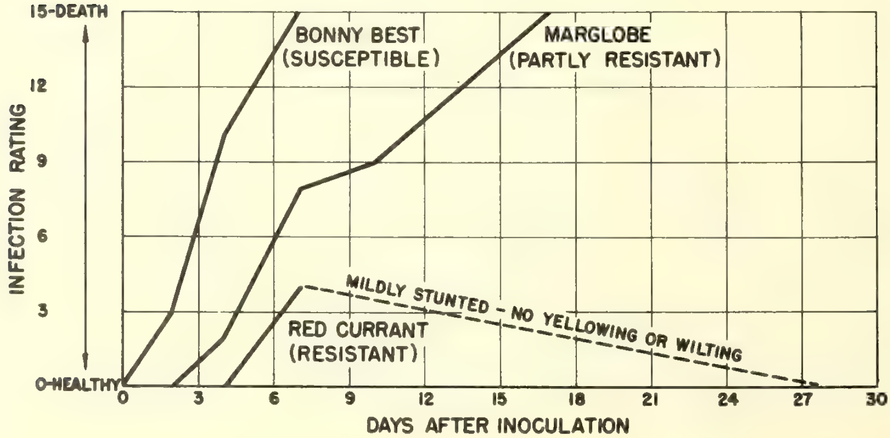


Figure 8. Tempo of tomato wilt development in 3 varieties of different wilt reactions. (After WELLMAN, 1939)

variety, and a tempo curve of entirely different character for a highly resistant variety.

As in many other sections of this book, this one can do little more than introduce the topic, point out the usefulness of, and need for, studies of disease tempo, and deplore the fact that "so many have contributed so little to this very important subject." There is golden opportunity for productive work in this branch of plant disease science that links loss appraisal with the ecology of plant disease.

Chapter IV

TECHNIQUES FOR DETERMINING PLANT DISEASE INTENSITY

INTRODUCTION: -- Basically the problem of plant disease loss appraisal consists of measurement of disease intensity and translation of this into loss. The present chapter is concerned with the methods of measuring and recording disease intensity while the following chapter deals with sampling and the organization of disease intensity surveys.

By disease intensity is meant the amount of disease present on a plant, in a field, or in a geographic region, without reference to the damage caused. BRIERLEY (in BEAUMONT et al., 1933) has protested that the phrase "measurement of disease intensity" is ambiguous, comprising two distinct conceptions, distinguished as " 'extensity' which is largely a matter of distribution and rate of increase of the disease, and 'intensity' which is largely a measure of lethality or damage done to that portion or product for which the given crop is cultivated."

These conceptions are followed in this book, but not BRIERLEY'S terms, since they are inappropriate by dictionary definitions, which interpret intensity as "quantity or amount" and extensity as "quality of extension". The concept which BRIERLEY designated "intensity" is here termed damage, destructiveness, or loss.

TEHON and STOUT (1930) have distinguished two components of disease intensity. They limit the term "intensity" to the amount of disease on individual plants, and couple this with "prevalence", the percent of plants affected, to give the disease index as a measure of the amount of disease present. NAUMOV (1924) has analyzed the problem somewhat differently. He distinguishes the degree of infection of the population, as percent, and the degree of infection of plant parts, which may be 100% or unity with those diseases where the plant or plant part is either totally diseased or totally healthy (head smuts, plum pockets, etc.). If the plant parts are partially infected, the degree of infection may be expressed as percent (ergot) or a scale of infection may be used (rusts). He has divided all cases of disease into two classes: (a) where infection of plant parts is total and we are interested only in the degree of infection of the population, and (b) where we are interested in the degree of infection of the plant parts, as in rusts, mildews, leaf spots, and some scab diseases. He has recognized that some diseases fall into different classes at different times. There should be recognized a third, intermediate class, in which a part of the population is infected with disease which on any one plant, destroys some fraction but not all of the commercially valuable organs or tissues. As we will see, the methods of appraising disease intensity vary from one to another of these three classes of disease.

In plant pathology there are many points at which measures of disease intensity are needed, as in scoring disease reactions of crop varieties or response of plants to disease control measures or in studies of the epiphytology of plant disease, as well as in loss appraisal. It has frequently happened that methods of determining disease intensity have been worked out for other purposes than loss studies, and the latter can often profit by taking advantage of techniques of disease intensity measurement that have been developed for some other, distinct use.

Methods of appraising the intensity of plant diseases for the most part have developed Topsy-fashion, without any general plan or coordination, each worker devising or adopting the methods that have appeared suitable, with the result that studies or data of several workers on a single problem cannot be compared, because different measures of disease intensity have been used.

There have been a few cases in which workers have been directed or urged to use a uniform system of scaling disease intensity, as in the case of the U. S. Department of Agriculture's field notebook for scoring cereal diseases, and in recent years plant pathologists of the British Mycological Society have been striving toward uniform methods of scoring such important diseases as cereal smuts, apple scab, and potato late blight.

The American Phytopathological Society made an abortive effort in this direction from 1917 to 1920 (Phytopathology 7: 149; 8: 179; 9: 182; 10: 265). In 1917 there was appointed a "Committee on Standard Chart for Percentage Estimates of Injury to Diseased Plants" with instructions to develop such devices and report at the next annual meeting. In 1918 this committee reported that it was making progress, and it was continued. In 1919 it made no report. In 1920 the committee: "Finds the chart now in general use by the Office of Cereal Pathology, U. S. Department of Agriculture, best adapted for most phytopathological purposes. It therefore brings this chart to the attention of the Society and recommends it as worthy of more general use." (This was the modified COBB scale designed for and limited to use with cereal rusts; see page 244 and Figure 12). The committee was then discharged.

NUMBER OR PERCENT OF DISEASED PLANTS, ORGANS, OR TISSUES AS A MEASURE OF DISEASE INTENSITY: -- When diseased plants or plant parts are total losses and not partial

losses, or when all diseased plants or plant parts are partial losses to the same degree, counts of diseased plants or plant parts and conversion of the counts into percent give accurate measures of disease intensity. Thus we find this method of scoring disease intensity most useful and reliable in dealing with: (a) diseases where the entire plant is rapidly killed, with few plants exhibiting partial loss, as in Fusarium wilt diseases of cotton and other crops, bacterial wilt of alfalfa, Texas root rot, barley stripe, and damping-off of seedlings; (b) cases in which diseased plants, while not killed, are all injured to approximately the same extent, as in virus diseases of vegetatively-propagated plants, excluding current-season infections; (c) instances in which the percent of infected plants is well correlated with the degree of injury, as with corn smut (see page 225); (d) diseases which cause total, not partial, destruction of the commercially valuable parts, as with the head smuts of small grains; (e) diseases in which plants or organs, even if lightly infected, are total losses from the commercial standpoint, such as crown gall of nursery stock, ear smut of sweet corn, brown rot of stone fruits, celery stalk blights, and the anthracnose diseases of tomato and watermelon; and (f) cases in which diseased plants or tissues are so rare that differences in degree of infection have little statistical significance.

The reverse procedure, of counting and determining the percent of healthy plants or tissues, is standard practice with some diseases of these types, for instance in studies of seedling disease where counts of emerged, healthy seedlings constitute the record.

Disease intensity (or loss) data on crop commodities after harvest, expressed as number or percent of market units, are often very helpful in comparing disease in different seasons or localities, though they do not represent total disease intensity because the most heavily diseased products do not enter market channels. Examples of useful data of this type include the Federal Grain Inspector's reports of numbers of carlots of smutty wheat, ergoty rye, and blighted barley, or shipping-point records of numbers of carloads of watermelons rejected for shipment because of anthracnose.

Numbers of diseased plants alone, even when percent of disease is not known, may at times be quite useful. It is very significant, for example, to have the records that in 1944, 20,000 elms in Dayton, Ohio and 10,000 in Columbus, Ohio were killed by the virus disease phloem necrosis.

When a disease is very scarce it may be impractical to determine percent of infection and the number of infected plants found under stated conditions may be the only available record. It is customary in reporting very light infestations of cereal rusts, for example, to note the number of rusted plants or plant parts found in a search of 10 minutes, 30 minutes, etc. The British workers frequently make use of conversion constants by which the number of diseased plants found within a given small area can be converted into approximate percent of infection, assuming a constant stand. With potato virus diseases, 0-0.1% is scored if one infected plant is seen within a 12-yard radius, and 0.1-1.0% if one diseased plant occurs within a 4-yard radius. For sugar beets the corresponding radii are 7 and 2 yards (Anon., 1943).

Descriptive scales of disease intensity are discussed in a later section, but it can be mentioned here that such scales sometimes are based on percent of disease incidence, as in WALKER and HARE'S survey of pea diseases (1943), where their scale of root disease was: "trace" = 1%, "slight" = 1-5%, "moderate" = 5-20%, and "severe" = 100% of plants with roots affected.

Wherever its use is valid, the recording of disease intensity as percent of plants or organs affected has the distinct advantages that it is uniform from one worker to another, provided a diseased plant or organ is properly defined, and that it is easily understood by all. But even the simplest methods have pitfalls, and in this case one is sometimes confused by reports of disease being present to the extent of a given percent when we have no means of knowing whether this is percent of plants with disease in any degree, percent of leaves, fruits, or other tissues affected, percent of leaf or fruit area involved, or percent with reference to some arbitrary scale, such as the COBB cereal rust scale. This fault may be seen in some of the reports of curcurbit downy mildew intensity.

The number or percent of diseased plants or organs is a less suitable measure of disease intensity when different plants or organs differ appreciably in their amounts of disease, or when, for any other reason, the amount of damage is not correlated with the percent of diseased plants or organs. Of the many cases of this kind there may be mentioned the cereal foot and root rots and rusts, leaf and fruit spot diseases in general, corn ear rots, wood decay, and root knot.

KOEHLER (1945) has pointed to the inexactness of many reports of corn ear rots which state only the percent of ears rotted in any degree, and has suggested the need for data on the estimated number or percent of kernels rotted per ear. Similarly HORSFALL and HEUBERGER (1942a), in dealing with tomato defoliation diseases, consider that data limited to the percent of diseased leaves have too low precision because of the varying number of lesions per leaf.

In cases such as these, a combination numerical method is often used. A good typical ex-

ample is the method used by TEHON and STOUT (1930) in surveying fruit diseases, in which records were taken of percent of trees affected, percent affected leaves, twigs, or fruits per tree, and average percent area, per organ, occupied by the disease. From such data a rather exact overall figure of disease intensity can be derived.

Another good device, where plants or organs differ in degree of attack, is to record the number of plants or organs in each of several disease percent classes, as 0-10%, 10.1-20%, ... 90.1-100%, and reduce this to a single numerical expression of disease intensity. HORSFALL (1945) has pointed out the advantage, in this case, of using classes based on the ability of the human eye to discriminate differences, such as the series: 0-3, 3-6, 6-12, 12-25, 25-50, 50-75, 75-87, 87-94, 94-97, and 97-100% disease. Classing of trees affected with wood decay is practiced in forest pathology, where the number of decayed or dead trees gives no true picture of the amount of decay or of loss.

Where loss is largely in the form of reduced commercial grade of a commodity, a good measure of disease intensity is the percent of products falling into each of several commercial grades. This is a common way of recording intensity of superficial diseases of potato tubers and fruits.

Where disease lesions are small and numerous, or coalescent, it is usually impractical to count or measure them, and some method of estimating must be used. Diagrammatic scales for this purpose are discussed below, and here it may be mentioned that the better scales, such as the COBB cereal rust scale, state for each grade of disease the percent of tissue involved by lesions, as found by measurement, which gives one the basis for translating scale readings into actual percent of diseased tissues.

With leaf-cast diseases the estimated percent of defoliation is a promising measure of disease intensity that has been too little used. It will be seen later that percent of defoliation is frequently well correlated with the intensity of disease on leaves that have not yet been dropped.

DESCRIPTIVE SCALES FOR EVALUATING DISEASE INTENSITY: -- Many workers, dealing with many kinds of plant disease, have found it advantageous to grade disease intensities in a number of arbitrary classes, which, if properly defined or described, represent a uniform method of data-taking and one which is comparable from one worker, location, or season to another. In the course of this study such descriptive scales, of varying quality, were found for sixty different diseases, and doubtless they have been used for many other diseases. The various types of scales used in appraising cereal rusts are considered separately in a later section.

The simplest type of descriptive scale, which, unfortunately, is still sometimes used, is to grade disease in three or more classes under such terms as "light", "moderate", and "severe", and sometimes, to make matters worse, the descriptive word is omitted and the undescribed classes are simply numbered or ascribed symbols such as "-", "±", and "+", or "+", "++", "+++", "++++". Such scales may be meaningless to workers other than the ones who devised them, since "moderate" disease in a region or season in which the disease is very prevalent may correspond to "severe" disease in a year or location with less abundant disease. In general such scales are useful only for recording relative disease differences observed by a single worker in a single location or season.

An example of such an inadequate scale is that adopted by the Alfalfa Improvement Conference (NEWELL and TYSDAL, 1945). This scale, designed by, and intended principally for the use of, agronomists, recognizes the classes: "1 (very little)"------"5 (medium)------ "9 (very much)", which are used, without further description, for scoring intensities of all alfalfa diseases, except bacterial wilt, in the Uniform Alfalfa Nurseries. All other alfalfa plant characters that cannot be recorded by percent are also scored on the 1-9 basis, which gives uniform-appearing records that can be easily averaged for many locations. In actual use this method of scoring disease is far from uniform. It may show relative differences between varieties, but whole groups of varieties or nurseries with similar amounts of infection may be rated as severely affected at one location and only lightly at another because the observers do not have a common understanding as to what constitutes "little", "medium", or "much" infection. This criticism applies to any scale in which the disease grades are not described so that independent observers can place similarly affected plants in the same disease class.

A descriptive scale may also be inadequate if the description of each grade is not realistic, recognizable, and usable in practice. This defect is illustrated by the prescribed grades of severity of infection of "miscellaneous diseases" of cereals in the "Cereal Disease Field Notebook" which was formerly widely used by U. S. Department of Agriculture cerealists and cooperators. This scale reads:

0 = absence of infection

1 = very slight, -- one or two specimens per acre
2 = slight, -- 8-10 specimens per acre
3 = considerable, -- 30-40 specimens per acre
4 = abundant, -- 25 percent to 50 percent of plants diseased
5 = very abundant, -- more than 50 percent of plants diseased

Here grades "4" and "5" are well understood. Grades "1" to "3" are meaningless, practically, since there are often more than 800,000 tillers per acre in a field of small-grain and it is obviously impractical to examine this many tillers, nor have these differences any practical importance. Furthermore, there is an enormous gap between grade "3" and grade "4". Grade "2" represents approximately five times as much disease as grade "1", grade "3" about four times as much as grade "2", and grade "5" about twice as much as grade "4", but grade "4" contains 2,000 times as much disease as grade "3", assuming that a "specimen" is a 5-tiller plant.

The need for, and striving toward, better scales of disease intensity are seen in the evolutionary improvement of scales, sometimes even in the methods of a single investigator. HORSFALL and his coworkers have made several improvements on their earliest methods of disease appraisal, and WILSON (1944), during six years of celery blight experiments, successively used four methods of scaling disease intensity, each better than the preceding one.

The following scale for potato late blight (Phytophthora infestans), developed by the subcommittee on disease measurement of the British Mycological Society is given as an example of a well-devised and useful descriptive scale, which should result in uniform, comparable disease records from different observers, locations, and seasons:

Notation	Degree of disease intensity
0.0	Not seen in field.
0.1	Only few plants affected here and there; up to 1-2 spots in 12 yd. radius.
1.0	Up to 10 spots per plant or general light spotting.
5.0	About 50 spots per plant or up to 1 leaflet in 10
25.0	Nearly every leaflet with lesions; plants still of normal form; field may smell of blight but looks green though every plant affected.
50.0	Every plant affected and about one half of leaf area destroyed; field looks green, flecked with brown.
75.0	About three-fourths of leaf area destroyed; field looks neither green nor brown. In some varieties the youngest leaves escape infection, so that green color is more conspicuous than in varieties like King Edward, which commonly show severe shoot infection.
95.0	Only few green leaves remaining, but stems green.
100.0	All leaves dead; stems dead or dying.

The value of such a scale is enhanced if it is accompanied by photographs or drawings illustrating the several grades, as discussed in the next section. Combination descriptive-diagrammatic scales have been developed for cereal root rots by GREANEY and MACHACEK (1935), for root knot by TAYLOR (1941), and for corn leaf blight by ULLSTRUP et al. (1945). Another helpful device is to have each scale class refer to a countable or measurable degree of disease, such as percent of leaf or fruit area involved in lesions or percent of roots affected by root knot.

Some workers have found it desirable to have two scales applying to different aspects of a disease, giving an opportunity to select the method best suited to the conditions of observation. TOWNSEND and HEUBERGER (1943), for example have described two methods of scoring the intensity of celery blight, one based on a classification of affected leaves and the other for scoring plots directly. Both had similar accuracy and the latter was chosen as being much more rapid. With leaf diseases one scale may be based on the degree of leaf involvement by disease and another on leaf death and defoliation, and with diseases that affect two or more types of organs, such as apple scab, it is helpful to have a scale for each of these.

In the preceding chapter it was pointed out that the stage of development of a plant at the time of its attack with a given intensity of disease is important in determining the amount of loss. Recognizing this, some investigators have made good use of companion scales, one for disease

intensity, the other for growth stage. GASSNER'S growth-disease scale for cereal rusts is mentioned later. The double scale of ANDERSEN (1946) for lettuce tipburn is a good illustration of this type:

Tipburn severity ratings	Leaf age ratings
1 - Very slight spotting in 1-2 leaves of age 5-7.	Age 3 - Leaves 1-2 inches in diameter. No chlorophyll.
3 - Slight spotting in 2-3 leaves of age 5-7.	Age 5 - The larger leaves tightly folded in the head. Usually no chlorophyll.
5 - Slight spotting in most leaves of age 5-7.	
7 - Spotting in most leaves of ages 5-7 plus some slime.	Age 7 - The head wrapper leaves only partly devoid of chlorophyll.
9 - Spotting in large leaves of age 3 as well as those of age 5-7, with much slime.	

DISEASE INTENSITY STANDARDS: -- A high degree of uniformity in rating disease intensity is possible when use is made of standards, including photographs, drawings, or preserved specimens, representative of each of a series of grades of disease intensity. In the course of this study a score of these objective aids to disease intensity rating have been found, with or without supplementary descriptions, and of varying quality and usefulness. Many more are needed for uniform scoring of diverse plant diseases, so that each observer may know what others mean by their disease classes, so that we may know how severe is "severe".

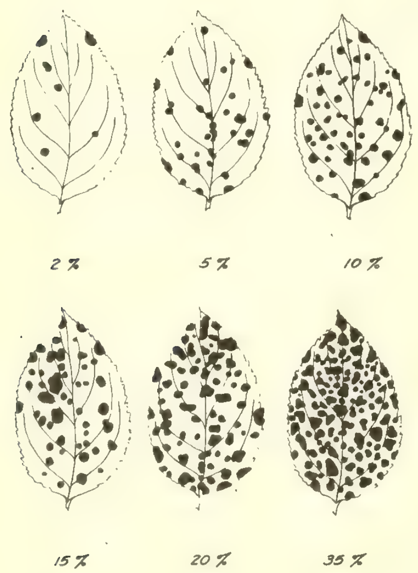


Figure 9. Diagrammatic scale for appraising black rot intensity on apple leaves. (After TEHON and STOUT, 1930. Courtesy, Illinois Natural History Survey.)

Omitting, for the moment, the cereal rust scales, pioneer work in devising disease intensity standards was done by TEHON (1927) and TEHON and STOUT (1930) in connection with their plant disease surveys of Illinois. They have furnished us with excellent series of standards in the form of line drawings, illustrating disease intensity grades for Septoria leaf spot of wheat, halo blight of oats, cherry and plum leaf spots, diffuse and spot types of apple scab, apple blotch, the leaf phase of apple black rot, and bacterial spot of peach leaves. One of these is included here in Figure 9 and other scales mentioned in the present section are reproduced in the chapters on source data. Comparable standards for apple rust have been devised by BLISS (1933) and P. R. MILLER (1934). A planimeter may be used for measuring the areas of lesions and of leaves, or advantage may be taken of other technical aids such as the apparatus for making leaf drawings described by STANILAND (1946). Technical suggestions that apply to this problem will be found in the discussion of artificial defoliation experiments (page 309).

In construction of their leaf disease standards, TEHON and STOUT attempted to imitate the size, shape, and distribution of disease lesions, and measured the total area of all lesions on each standard leaf to obtain the percent of leaf tissue involved in lesions in each scale grade.

In another good type of diagrammatic standard the entire plant is shown, giving one a conception of the distribution of disease over the plant as a whole. This is very well illustrated by the scale for estimating

Figure 10. Diagrammatic scale for appraising intensity of Helminthosporium turcicum leaf blight on corn. (After ULLSTRUP et al., 1945). Courtesy, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture.)

Helminthosporium turcicum leaf blight of corn prepared by the Committee on Methods for Reporting Corn Disease Ratings (ULLSTRUP, ELLIOTT, and HOPPE, 1945). The scale is presented in Figure 10 and is supplemented by descriptions of each of the six disease-intensity classes. A comparable diagrammatic scale of the stalks of tomato plants with 14 degrees of wilt attack (Fusarium) has been furnished by WELLMAN (1939). This, like some of the other scales, was originally planned to aid in scoring degrees of disease resistance, but may also be used in appraising disease for other purposes.

A number of other investigators have used actual photographs of diseased leaves, fruits, roots, or plants to compose graded series for rating disease intensities or reactions. Typical of these is the chart prepared by TRUMBOWER (1934), illustrating six degrees of attack of elm leaves by Gleoosporium inconspicuum, presented here as Figure 11. He has also given a comparable scale for the Gnomonia ulmea leaf spot of elm, and other photographic scales that are available include those of rubber leaf blight (LANGFORD, 1945), root knot (BARRONS, 1938; TAYLOR, 1941), cereal root rot (GREANEY and MACHACEK, 1935), and bacterial blight of cotton on cotyledons, leaves, and bolls (RAY, 1945). For a somewhat different type of problem, VASUDEVA (1946) has published a series of photographs of five degrees of attack of potato by mosaic. In this case all grades of plants are totally diseased but each grade represents a different degree of plant reaction, owing to presence of different virus strains, and such a scale is helpful in determining loss since loss varies with severity of plant reaction.

CEREAL RUST SCALES AND THEIR USE: -- The first scale to be developed for appraising

Figure 11. Photographic scale for appraising intensity of Gloeosporium leaf spot of elm. (After TRUMBOWER, 1934).

cereal rusts was that of the Australian, COBB, in 1890-1894. It showed diagrammatically 5 degrees of rust intensity ranging from 1% to 50% leaf coverage by pustules and was used chiefly for leaf rusts. In 1917 MELCHERS referred to the "newly adopted U. S. Department of Agriculture scale", and in 1922 he and PARKER published a photograph of the "U. S. D. A. rust scale" which proved to be a slightly altered copy of the COBB scale with the addition of one degree of rustiness and the substitution of a series of percent equivalents with the highest value 100%, representing the maximum rust concentration and corresponding to actual coverage of 37% of the leaf surface with pustules. This modified COBB scale, which has also been called the "American scale" and the "scale of MELCHERS and PARKER", together with the original COBB scale, are presented here in Figure 12.

This scale became very widely used in America through distribution, by the U. S. Department of Agriculture, of a large number of copies of the "Cereal Disease Field Notebook", containing it, and it is still the basis for most American leaf and stem rust ratings. For more exact leaf rust appraisals WALDRON (1936) examined representative leaves under the low power microscope, counted and measured pustules in areas 11 x 20 mm, computed the areas occupied by pustules, and translated this into percent intensity according to the arbitrary percent values of the modified COBB scale.

The "Cereal Disease Field Notebook" directs workers to gather a number of leaves at random and examine a number of plants carefully for stem rust, compare with the diagrams, and record the rust intensities. This lack of specific directions has led to some lack of uniformity in rust reports, since one worker may select average leaves, regardless of location on the plant, another may confine attention to the rank of leaves most typically rusted at the time of inspection, and a third may deliberately select the more heavily rusted tissues. If a sample is intermediate between the 40% and 65% stages, one worker assigns the value 65%, since this is nearer; another (e.g., TEHON, 1927) assigns 40%, selecting the lower grade for intermediate samples by rule; while a third would report this sample by an estimated intermediate value, such as 55%.

The modified COBB scale has been criticized by some European workers, notably NAUMOV (1924) and RUSAKOV (1927) in Russia. The former objects that the scale is "rough, schematic, and rarely will one find such a distribution of pustules." This is true; stem rust and leaf rust pustules are entirely different in shape and the latter tend to be concentrated in some stem areas and scarce in others. In actual practice, however, this does not seem to be a handicap, as the writer has many times observed in comparing the rather uniform rust readings of the same samples, made by two or more independent observers who have been trained in comparable use of the scale.

RUSAKOV'S additional objection is that the modified COBB scale does not have a sufficient

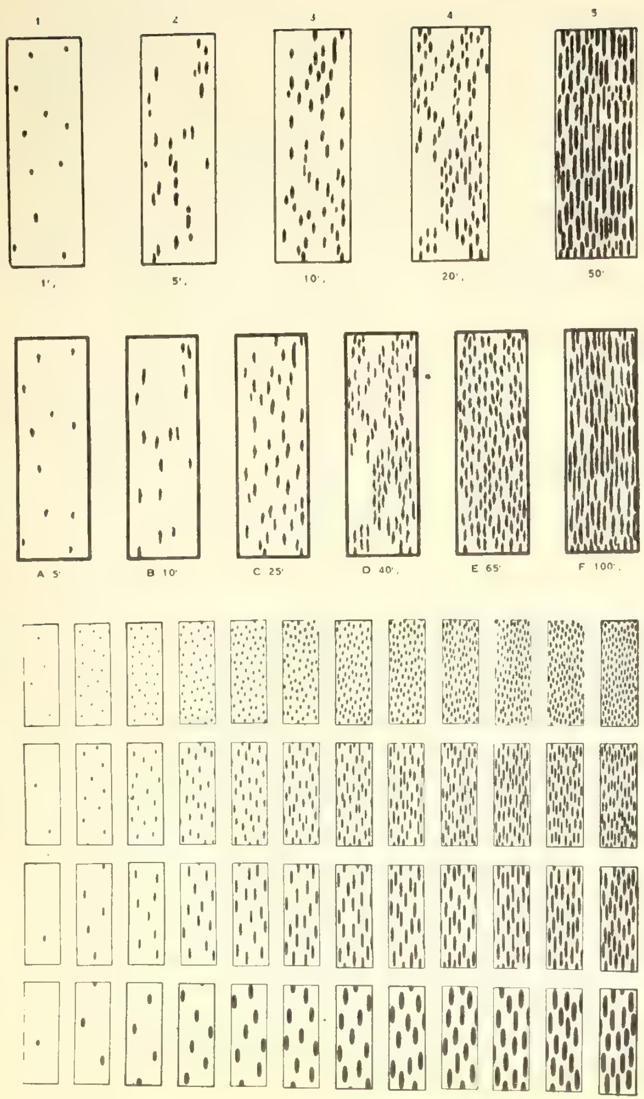
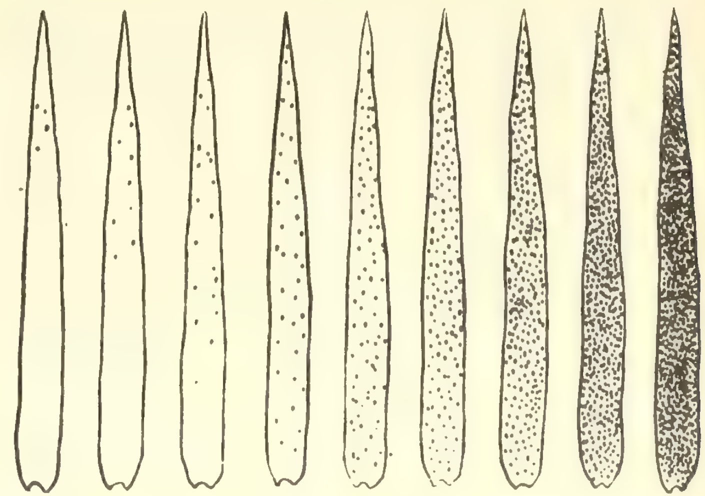


Figure 12 (left). Above: Original COBB scale for estimating cereal rust. (After COBB, 1890-94.) Center: Modified COBB rust scale of the U. S. Dept. of Agriculture. (After MELCHERS and PARKER, 1922.) Below: Canadian scale for cereal rust estimation. This was published in three sizes to facilitate rust appraisal under conditions of different pustule size. (After PETERSON et al., 1948. Courtesy, Canadian Journal of Research.)



RUSSIAN UNITS:	1	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3	$3\frac{1}{4}$	$3\frac{1}{2}$	$3\frac{3}{4}$	4
EQUIVALENT TO NO. PUSTULES:	1-5	6-12	13-25	26-50	51-100	101-175	176-325	326-500	OVER 500
CORRESPONDING VALUES IN COBB SCALE:	—	—	—	1%	5%	10%	20%	—	50%
CORRESPONDING VALUES IN USDA MODIFICATION OF COBB SCALE:	—	—	—	5%	10%	25%	40%	65%	100%

Figure 13. Russian scale for cereal rust estimation. (After RUSAKOV, 1927.)

number of grades at the lower end of the scale, which is valid if one is concerned with rust reproduction at levels of low rust intensity, although with very small amounts of rust it is usually more accurate and just as convenient to count pustules as it is to estimate their number by use of a diagrammatic scale.

In an endeavor to proceed in the direction of greater accuracy in determining degrees of rust intensity, RUSAKOV (1926, 1927, 1929b, 1929c) developed a new diagrammatic scale, which has since been widely accepted and used by Russian workers. Figure 13 shows this scale, with its 9 grades of rustiness, the numerical symbols for noting each, the number of pustules per leaf corresponding to each grade, and the approximate equivalents on the modified COBB scale. It is seen that RUSAKOV'S scale includes three degrees of rustiness in the low rust range that have no counterpart in the other scales, in accordance with his observation that 10, 15, and 20 rust pustules per leaf respectively in the early period of rust development may lead to major differences in grain yields in the three cases.

The Russian scale has degrees of rustiness that progress in logarithmic order in accordance with the mode of rust reproduction and the ability of the eye to discriminate differences. Each stage represents approximately double the number of rust pustules per leaf as that of the next lower stage. To reduce the system of Russian units of estimation to values indicating the rustiness of whole plants, RUSAKOV has furnished the "equivalent units" shown in Figure 13, each unit corresponding to 250 rust pustules.

Most recently, PETERSON et al. (1948) have presented a new cereal rust scale, reproduced in Figure 13, with the advantages of showing 12 rust intensities for each of four classes of pustule size and shape. This is a step forward, but the use of logarithmic, rather than arithmetic intervals would be preferable, since the difference between the 70% and 80% grades, for example, is hardly perceptible, while that between the 10% and 20% grades is readily observed.

Parallel with the development of these diagrammatic rust scales, a series of descriptive rust scales have been proposed by other workers. The first of these was the scale of ERIKSSON and HENNING in 1896, which recognized four numbered degrees of rust intensity described as "trace", "sparse", "moderately abundant", and "abundant". A similar scale was recommended by YACHEVSKI in 1909, and another, but with six rust grades, by NILSSON-EHLE in 1911. LITVINOV'S descriptive rust scale (1912) had seven rust grades and was distinct in its application to the whole plant rather than to single leaves. The scale proposed by DUCOMET and FOEX in 1925 also had seven stages, ranging from "trace" to "enormous".

VAVILOV (1913, 1919, 1935) attempted to devise a scale reflecting both rust intensity and host reaction to rust, which assumes that there is a correlation between increasing number of rust pustules and increasing rust susceptibility. He published (1935) colored plates of his scales for wheat leaf and stripe rusts. The weakness of such a scale is the fact that rust intensity and rust reaction often are not correlated. There may be many resistant-type rust pustules on one plant and few susceptible-type pustules on another. Most present-day observers record rust intensity and rust reaction separately, and use the records for different purposes.

In 1915 GASSNER, agreeing with NILSSON-EHLE that four grades of rustiness do not give sufficient diversity, proposed an 8-grade scale (1 = minimum..... 3 = weak..... 6 = strong..... 8 = exceptionally strong) which had the novel and useful feature of being supplemented by a 10-grade scale of stages of host plant development, noted in Roman numerals. In his notation, "5 VIII", for example, indicated medium rust infection when the host plant was in the post-blossoming stage. This scale is also the first in which is recognized the importance of having rust grades arranged in logarithmic progression.

When rust intensity is at a very low level, some workers, such as RUSAKOV (1929a), report the number of rusted plants or of pustules found in a search of a given length of time, often five or ten minutes. This is not very satisfactory because of marked individual differences in power of observation. A better procedure is to collect leaves at random, sometimes several thousand being required for one observation, and record the number of pustules and of leaves. Since readings using the modified COBB scale can be expressed in number of pustules per leaf, this procedure gives figures which can be compared statistically over as great a range as a millionfold. For example, the level of rust in Stillwater, Oklahoma during the first week of April, 1948 was appraised at 1 pustule per 5000 leaves, while during the corresponding week of 1938 it was approximately 200 pustules per leaf, i.e., 1: 1,000,000.

The existence of so many rust scales is a reflection on the unsettled state of appraisal methods. If it is the prerogative of any worker to devise a new scale when existing ones are unsatisfactory, it is also an obligation for him to use an existing scale, when available and suitable, rather than to burden the literature and increase the complexity and lack of uniformity of disease intensity data by proposing new scales which have no significant advantage over existing ones.

The time-tested usefulness of the modified COBB scale, or, if preferred, the RUSAKOV

scale or that of PETERSON et al., and their objective character, warrant their continued use as standard devices, with the discarding of all cereal rust scales which are not diagrammatic, and therefore vary with the conceptions of the users.

The procedure of cereal rust appraisal has been discussed by CHESTER (1944). Rust infestations, except in early stages, are usually quite uniform in individual fields of one host variety, and in ordinary surveying it is usually sufficient to gather a dozen leaves or stems at random and select the point on the scale which comes closest to the average rust intensity for the sample. Where rust is scarce or in the form of scattered infection foci, larger samples, up to several hundred leaves or stems, should be taken, and where it is at a very low level thousands of specimens may need to be examined and the leaves and pustules counted.

Several of the European workers have given more or less elaborate directions for separately scoring the various parts of the plant and then combining the scores to give a single numerical value to the plant as a whole. In some types of studies this is justified, as in investigating differences in the behavior of different host varieties, but the labor involved is so great that such a procedure strictly limits the appraising which may be done, and for surveying rust intensity on a broad scale it is believed that the advantage of being able to sample many fields over a broad area outweighs the advantage of having a highly precise measurement of rust on a few plants from very few locations.

In common practice of sampling for leaf rusts it is neither necessary nor desirable that the leaves be collected at random from all heights of insertion. Until after the blossoming stage, the uppermost leaves have not had time to become infected, while the lowest leaves do not give a true picture of rust intensity since they are no longer functional. It is best to select the samples from the one or two ranks of leaves that have had full time for rust expression, but which have not yet begun to die. It is usually quite obvious which ranks these will be, but if there is any doubt the samples may be taken from all probably useful ranks. It is very helpful to others if rust intensity reports given information on how the samples have been taken.

LOGARITHMIC VERSUS ARITHMETIC STAGES IN DISEASE INTENSITY SCALES; PROBITS: -- Many insect pests and agents of plant disease multiply at geometric rates as time advances by arithmetic degrees. Such behavior may be best recorded by using a logarithmic scale. In the case of rust diseases, for example, the increase from one to ten pustules per leaf consumes as much time and has as much importance biologically as the increase from 10 to 100 to 1000 pustules. A logarithmic scale attaches equal importance to each of these increases, while on an arithmetic scale the increase from one to ten pustules would appear to have no more significance than the increase from 991 to 1000 pustules.

The visual acuity of the human eye is also so adapted that we can perceive differences of equal spread on a logarithmic scale with more or less equal ability, but not differences of equal spread on an arithmetic scale. For both these reasons, then, a logarithmic scale is preferable to an arithmetic one in observing and recording absolute differences in disease intensity.

This principle has been observed in construction of a number of the better disease-intensity scales. With the cereal rusts, GASSNER'S (1915) scale has stages 1, 3, 5, and 7 corresponding to .05, .5, 5-15, and 40-50% leaf coverage respectively, and RUSAKOV'S scale is roughly logarithmic, with the number of pustules per leaf progressively increasing by the steps: 1-5, 6-12, 13-25, 26-50, 51-100, 101-175, 176-325, 326-500, and over 500. Leaf diseases of tomato, cucumber, grape, and potato are all rated by recent workers in Palestine on a scale of disease units of the form: 0, 0.1, 0.5, 1.0, 2.0, 4.0, 8.0, (REICHERT et al., 1942a, b, 1944; LITTAUER et al., 1946).

Where percent disease, rather than absolute amount of disease, is recorded, a probability scale is sometimes used. This is a scale in which the units pass through 1 1/2 logarithmic phases in each direction from the 50% point, on which equal linear distances are called equal probability units or "probits". This method of recording disease intensity was developed by HORSFALL and BARRATT (1945) and has been discussed at length by HORSFALL (1945).

Twelve grades of disease, in percent, are recognized, viz. grade 1 = 0%, 2 = 0-3, 3 = 3-6, 4 = 6-12, 5 = 12-25, 6 = 25-50, 7 = 50-75, 8 = 75-87, 9 = 87-94, 10 = 94-97, 11 = 97-100, and grade 12 = 100% disease. Plotting disease percent and grade on an arithmetic-probability grid gives the linear relationship shown in Figure 14, which is used as a calibration curve for converting graded disease readings into percent.

As HORSFALL has pointed out, such a series of grades follows the WEBER-FECHNER law that visual acuity depends on the logarithm of the intensity of the stimulus. "In grading plant disease the stimulus changes at the 50% level. Below 50%, the eye sees the affected tissue, but above 50% it sees the healthy tissue......Although it hardly seems possible at first that one can read differences of three percent at the end of the scale as easily as a difference of 25 percent in

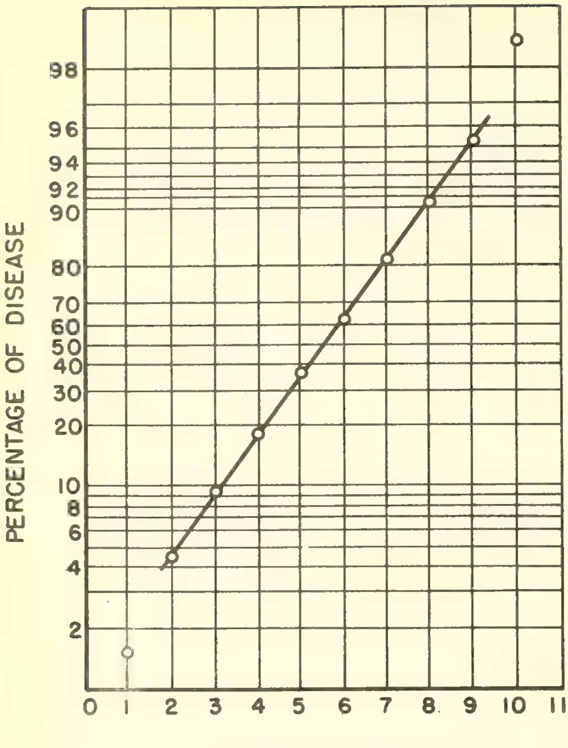


Figure 14. Calibration curve for converting graded disease readings into percentage, illustrating the use of the arithmetic -- probability grid. (After HORSFALL, 1945).

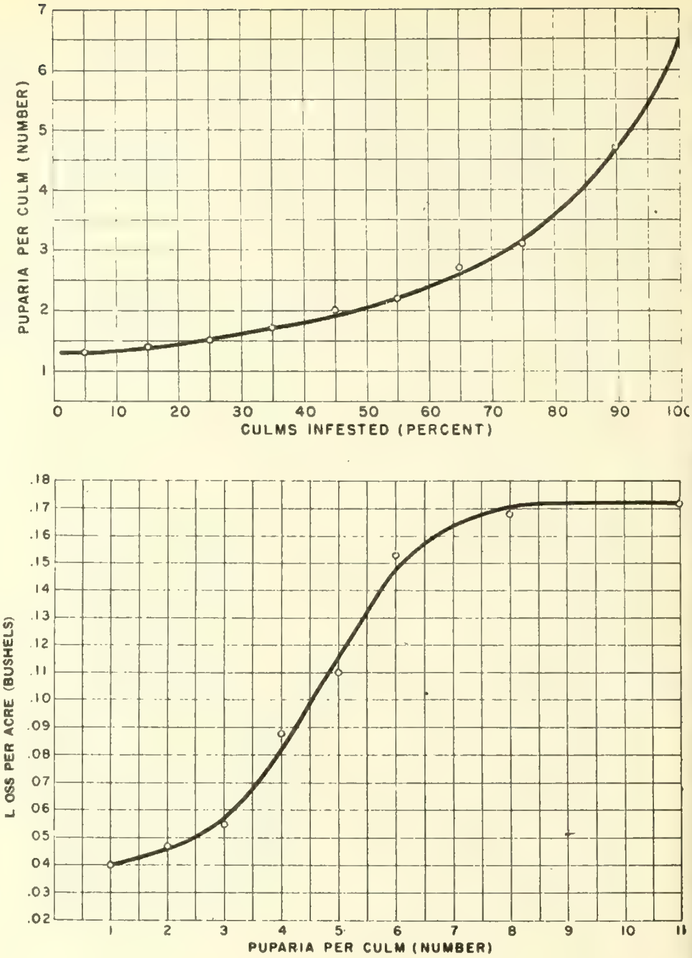


Figure 15. Curves relating percent of wheat culms infested with Hessian fly puparia, number of puparia per culm, and loss in yield. (After HILL et al., 1943.)

the middle, experience shows that actually is the case" (l.c., p. 39.)

HORSFALL'S probability series of disease grades appears to be well suited to use with some types of experiments, particularly in assessing field experiments with fungicides. But from the standpoint of disease appraisal, aimed at determining loss, it has a serious defect, since the different disease classes that are equally well discriminated have great differences in economic significance. The difference between 20 and 80% of leaf tissue destroyed has far greater economic significance than the difference between 2 and 12%, which ranges have equal emphasis on the probability scale. For practical loss determination we need more disease grades between 20 and 80% than between 2 and 12 percent, which this scale does not provide. The other horn of the dilemma is this: What is the use of having more grades than the eye can distinguish?

We obviously cannot do without subdivisions in the middle of the probability scale. The solution of this problem may be to use technical aids to estimation when working in this middle range such as diagrammatic scales, increased numbers of samples, and greater effort generally.

CORRELATIONS OF DIFFERENT EXPRESSIONS OF DISEASE: -- It would be very helpful in many cases of disease appraisal if two or more expressions of disease were well correlated with one another. If there should be a high degree of correlation between root decay and some aboveground symptom, for example, some of the labor and time involved in digging up and examining roots would be spared. If two observers should report intensities of a given disease in terms of two different expressions of disease which are well correlated, a valid comparison of

the reports could be made.

An excellent illustration of tests to determine correlations and apply these to loss estimation is to be found in the work of HILL, UDINE, and PINCKNEY (1943), and although they were concerned with insect infestation, the principles of their investigation have general applicability in plant pathology. Several thousand wheat culms were examined in a study of Hessian fly incidence and effects, and from the data obtained there were constructed the curves reproduced in Figure 15. Part "A" of the figure shows the good correlation observed between percent culms infested and number of fly puparia per culm, while part "B" equally well relates the number of puparia per culm to yield. Equipped with this information, the appraiser could determine yield reduction by fly damage knowing either the percent infested culms in a field or the average number of puparia per culm (in case his sample was a bundle of infested culms without data on percent of field infestation), or he could derive either of these values from the other. There are very analogous problems in plant pathology, such as the relation between percent of scabbed apples to amount of scab per apple, or between number of disease lesions per leaf and percent of leaves diseased in any degree.

NAUMOV (1924) considers it to be a general principle that there is a high correlation between percent of plants infected with disease in any degree, percent of organs infected, and severity of infection per organ. Many investigators have suggested that this principle applies to diseases which they have studied, but there appear to be very few records of determination of correlations comparable to those with the Hessian fly. Some of the descriptive scales of disease intensity also suggest such correlations, as that of ULLSTRUP _et al._ (1945) for _Helminthosporium turcicum_ leaf blight of corn, where the definitions of successive disease grades mention parallel increases in number of lesions per leaf and in number of diseased leaves per plant (Figure 10).

In his study of meadow crop diseases in 1930, HORSFALL regularly found a constant ratio between percent of healthy leaves, percent of leaves in various stages of disease, and percent of dead leaves. "If, for example, 60% of the leaves were infected, then about 15% of these would be dead, and the others would lie along an infection gradient from severely infected to healthy." In later work with tomato defoliation (HORSFALL and HEUBERGER, 1942_b_) he worked on the assumption that the percent of dead leaves is proportionate to the number of lesions, thus avoiding the excessively time-consuming work of counting individual lesions.

It seems very reasonable to suppose that there is often a regular correlation between these three measures of disease intensity, -- percent of plants affected, percent of organs per plant affected, and degree of infection per organ. Yet we cannot safely proceed merely on the basis of an assumption. If efforts could be made to determine the validity of these correlations for numerous types of disease, the results would have great value in disease appraisal, making it possible to select the easiest or most rapid of several alternate measures of disease intensity, or to convert data obtained by one type of measurement into estimates in terms of others.

As a good illustration of the value of correlations of this type, we have GODFREY'S (1934) study of appraisal of nematode populations in the soil. It is very time-consuming and impractical to do this by actually counting the organisms. GODFREY planted susceptible "indicator plants" in infected soil and demonstrated clearly that there is a high degree of correlation between percent of plants infected, number of nematode galls per plant, and nematode population in the soil. As a result it is possible to use the simple and rapid plant- or gall-counts and, by use of a suitable formula, to convert these into soil infestation values.

The prospect of establishing constant ratios between disease intensities of different organs of the same plant is subject to more exceptions. There are numerous diseases comparable to apple blotch in which there is independent variation in the amount of disease on leaves, twigs, and fruits. Apple varieties are classified differently according to their blotch susceptibility in these three types of organs. Apple bitter rot (_Glomerella cingulata_) shows the same situation. With such diseases as these, the several organs must each be appraised, since the amount of disease on one type of organ may give no valid index of the amount on another organ.

But we need not exclude the possibility of all correlations of diseased organs because they are lacking in some cases. HORSFALL and HEUBERGER (1942_a_) have shown a high positive correlation between tomato leaf damage and stem-end rot of the fruits, McNEW (1943_i_) has found late blight (_Phytophthora_) of tomato vines correlated with fruit rot, and LEWIS (1944) has reported a high correlation between spray injury of leaves and preharvest-drop of apple fruits.

Whenever, as in the latter case, the effect on one organ is the direct result of disease on another organ, a high correlation between the two may be expected. Numerous other typical examples are found in experiments on the effects of defoliation in reducing twig length and fruit, nut, or grain production (_cf._ SCHUSTER, 1933). A very practical use of such correlations is

seen in the analysis of annual rings of trees to determine the occurrence and severity of defoliation and other plant injuries in earlier years.

With the cereal rusts there are some useful correlations apart from that between rust and plant development or yield. CONNERS (1936) has advanced the principle that leaf rust of wheat attacks leaf sheaths more lightly than the leaves but in direct proportion to the leaf attacks. "It is suggested that the percentage infection found thereon may serve as an index to the susceptibility of the variety when it is impossible to estimate the infection on the blades late in the season on account of their shrivelled condition." RUSAKOV (1929b) holds that there is a correlation between intensity of the uredial stage and that of the telial stage of cereal rusts and that the latter is frequently a more suitable measure of rust intensity than the more commonly used uredial stage. This cannot be invariably true, because there are some regions where the telial stage of wheat leaf rust, for example, rarely occurs. RUSAKOV (1926, 1927, 1929b) has also stressed the correlation between leaf rust intensity and degree of killing of leaves. RUZINOV (1934) goes still farther in maintaining that there is such a high correlation between disease and culm length in cereals that loss from disease can be determined simply by classifying culms according to length group. Culm length is so well known to be affected by genetic and other factors that it is doubtful that so much reliance should be placed on this one plant character.

Canadian investigators have given particular attention to correlations in connection with cereal root rot diseases, where such correlations would be very useful if demonstrated. The results are somewhat uncertain, which may be partly due to variation in the types of root rot studied. BROADFOOT (1934) attempted to correlate root infection of wheat with color of the crown area. In general the color rating agreed with the infection rating, but there were some disparities, where the infection was greater than indicated by the color. SALLANS (1935), working with common root rot of wheat and barley, found that subcrown lesions were more significantly correlated with grain yield reduction than were lesions on the underground parts. Later he and LEDINGHAM (1943) reported that internal crown lesions and external lesions of plants with common root rot were not well correlated.

In forest pathology we find some of the best instances and uses of the correlations between different aspects of disease. Wood decay is the leading problem. Direct examination to determine the amount of decay within standing trees is costly and impractical except on a sampling basis, yet is it necessary to know the approximate amount of decay in order to determine value of the timber for specified uses and optimal cutting time to avoid serious losses from decay. Therefore much attention has been paid to correlations between decay volume and external symptoms or signs.

The presence of the fruiting bodies of wood decay fungi on tree trunks is not a very useful character because these tend to develop late in the decay process and may not be present in cases of serious decay. One old scaling practice for aspen has been for the timber cruiser to cull "heavily" if the trees are more than 15 inches in diameter and bear fruiting bodies and "lightly" if they are 8-14 inches in diameter and lack fruiting bodies, but this is regarded as too vague for good practice (R. M. BROWN, 1934). In general, age and size of the tree are correlated with decay, and BROWN has reported that in aspen there is a high correlation between per cent volume of rot, rot diameter, height of tree, age of tree, and its diameter, regardless of site or soil type. These findings agree, in general, with the earlier ones of MEINECKE (1929).

An excellent study on correlations in oak has been made by HEPTING (1941) and his associates (HEPTING et al., 1940) following a preliminary investigation by HEPTING and HEDGCOCK (1937). In the case of top or trunk rot they found a good correlation between rot and rotten branch stubs, surface injuries, and blind knots on the bole. Fruiting bodies were too rare to serve as the basis for risk classification. They devised a series of decay classes described in terms of these external features, and graphically related the classes to amount of cull (Figure 16).

In studying butt rot in oak, HEPTING found a high correlation between fire wounds and rot, and he was able to present curves (Figure 17) and a formula relating age and width of the wounds to the amount of butt cull, so that the amount of cull at the time of surveying could be determined readily, and the amount of cull at any given future data could be predicted.

An even more detailed study of correlations between external signs of defect and internal decay has been made by ZILLGITT and GEVORKIANTZ (1948), making it possible to determine cull in northern hardwoods, particularly sugar maple, by use of a table correlating 31 types and degrees of external defect with amount of internal defect.

These few examples bring out the value to disease appraisal practice of a knowledge of correlations between different manifestations of a disease. Yet the cases in which such correlations have been studied are far too few. Here is a good opportunity for the investigators of various plant diseases to make important contributions that will simplify or facilitate the appraisal of plant disease intensity and loss.

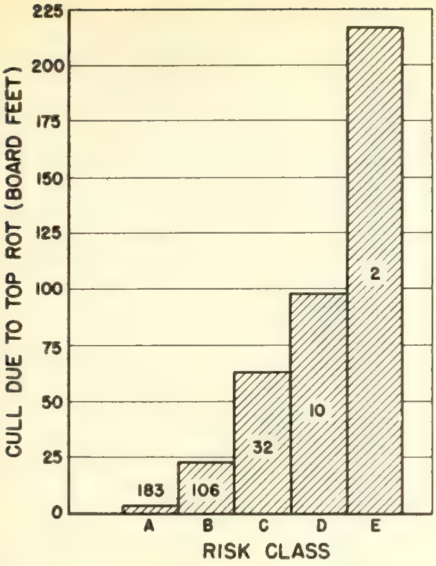


Figure 16. (left) Relation of risk class to cull due to top rot in Appalachian oaks. Classification of risk: A - No rotten stubs over 3" thick, no large surface wounds, no holes and less than 3 blind knots or healed stubs, anywhere on the bole up to 8 ft. above merchantable top; B - One rotten stub or large surface wound, or 3 blind knots; C - Two rotten stubs or large surface wounds, or 4 to 5 blind knots and stubs; D - Three rotten stubs or large surface wounds, or 6 to 7 blind knots and stubs; E - Four or more stubs and wounds or 8 or more blind knots and stubs. (After HEPTING et al., 1940. Courtesy, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agr.)

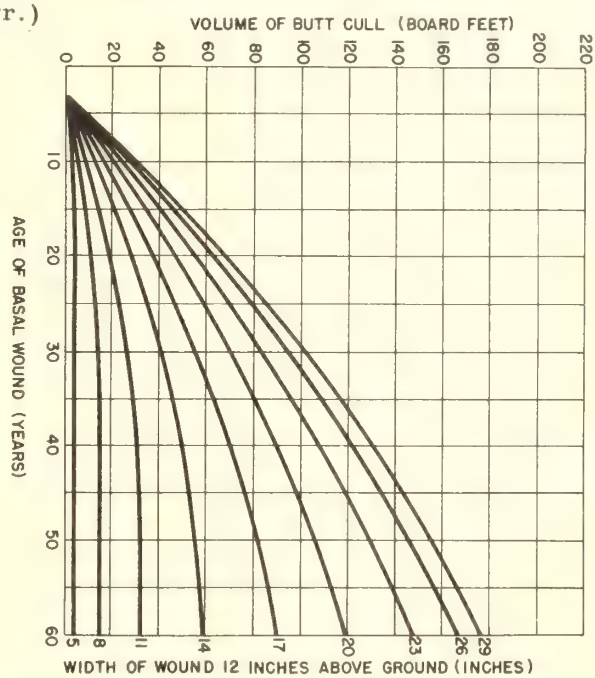


Figure 17. (right) Relation of butt - cull volume in board feet to age of basal wound for different wound widths, in Appalachian oaks. (After HEPTING, 1941.)

FOREST DISEASE APPRAISAL: -- This subject has been highly developed in forest pathology, having become a leading phase of forest mensuration. We have already seen instances of the progress in this field in the preceding section and in connection with disease forecasting. Since the subject of forest disease appraisal has been extensively treated in a number of text and reference books, it is not fitting to devote any considerable space to it here. The interested reader will find an excellent discussion of the subject in the chapter "Loss and Appraisal of Damage" in BAXTER'S book, Pathology in Forest Practice (1943).

Forest trees present certain unique problems in disease appraisal, including the irregularities in age, species, associations, terrain, and locations of trees, and the fact that wood decay, the leading problem, can be inspected directly only with much effort and expense. To solve these problems use is made of sampling techniques that are peculiar to forest pathology.

For determining the internal condition of a tree, use has long been made of the increment borer, which extracts a pencil-like core of wood, radially from bark to center of the tree, giving an index both of tree growth (annual rings) and amount and type of decay. Among new methods of internally sampling trees, RANKIN (1931) has described the use of X-rays and radiographs which successfully show slight amounts of decay in living trees. It would seem possible that radar might be used for the same purpose. Such methods avoid making injuries to the tree through which decay organisms could gain ingress, and might be particularly useful in determining the amount of decay in valuable shade trees.

Because of the uneven terrain and lack of roads in forests the autogyro and helicopter are particularly useful in determining the incidence of those diseases which can be recognized at a distance. A few years ago extensive surveys for the Dutch elm disease were made by autogyro, each suspected tree being located on a map and later examined minutely by a ground crew.

In forest sampling, particular care must be taken to obtain truly random samples, because of the irregular distribution of the trees. One method is to sample every tree, fifth tree, tenth

tree, etc., along a compass line.

MEASURE OF PATHOGEN CONTENT OF SOIL, WATER, AND AIR: -- Before undertaking culture of a crop in a location where it has not been grown previously or recently, it is frequently very desirable to determine the pathogen content of the soil. Serious losses may sometimes be avoided in this manner, and pathological soil sampling is therefore a necessary phase of disease appraisal. In general, one of three methods may be followed: (1) direct examination of soil to determine the presence of pathogens or their signs; (2) culturing soil with the aid of attractants or of culture media that have selective value in isolating particular soilborne pathogens; and (3) appraising the condition of health or disease of (a) wild plants growing in the soil in question, that are susceptible to the disease concerned or (b) indicator plants of susceptible species that are deliberately planted in the soil., outdoors or in the greenhouse, to determine the presence of given pathogens.

A good example of the first alternative is seen in the practice of sugar beet growers in the Sacramento Valley of California, who send soil samples to the Experiment Station laboratory at Davis for analysis of the content of sclerotia of Sclerotium rolfsii. A technique for quantitative determination of these sclerotia in soils was described by L. D. LEACH in 1934. A number of investigators have attempted to appraise the content of nematodes in soil by the direct method, washing and screening out the nematodes. GODFREY (1934) has found this to be too time-consuming and inaccurate for ordinary use, and has turned to the use of indicator plants, as mentioned below.

The second method is illustrated in YARWOOD'S (1946b) determination of the black root rot fungus, Thielaviopsis basicola, in soils by use of carrot slices covered with moist soil. Entomologists make extensive use of attractants in sampling for insects. Because most plant pathogens do not have power of free locomotion, this has little application in plant disease appraisal, but it would be interesting to determine whether attractants could be used in analyzing soil for the presence of plant-pathogenic nematodes.

The third alternative, that of examining wild or intentionally planted indicator plants, to detect the presence of pathogens, has many applications, and like the other two methods it could be developed profitably for more extensive use. Indicator plants are commonly used to determine the presence of root knot nematodes (Meloidogyne spp.) in soil. Wild hosts such as lamb's quarters may be helpful. The writer has frequently been called upon to analyze soil for root knot nematode content, to assist in selecting sites for nursery stock, orchards, or vegetable production. The procedure usually followed has been first to examine weeds on the location, and, if necessary, to take numerous soil samples and plant them, in the greenhouse, with several suspects, such as vetch, alfalfa, tomato, okra, and peas. The presence of the pathogen can usually be detected by knot formation in 25 to 30 days. Several species of indicator plants are used, in case the nematodes present exhibit host-group specialization.

This type of work has been put on a quantitative basis by GODFREY (1934), who has shown that it is possible to get reliable assays of the nematode populations of soils by making use of the high correlations that exist between percent of indicator plants infected, number of nematode galls per plant, and nematode population in the soil.

Analysis of soils for the presence of Aphanomyces cochlioides, cause of black root in sugar beets, by planting the soils with beet seed in the greenhouse, has been described by FINK (1948). He obtained a correlation of +.925 between percent of seedlings killed and field loss estimates, and the method therefore has promise in predicting sugar beet losses from this cause.

GOSS (1934) surveyed 100 Nebraska locations for presence of the organisms of potato scab and Fusarium wilt by planting a bushel of healthy potatoes at each location, to determine the prevalence of these soil-borne diseases in relation to cultural conditions.

These few examples illustrate the possibilities of including the sampling of soil in disease appraisal for determining and avoiding disease hazards. The field is one in which much more work could profitably be done.

Sampling of water to determine pathogen content has such great importance in human medicine as to constitute a subscience, -- water bacteriology. It is strange that there appears to be very little comparable work in plant pathology, limited to a few atypical cases, such as the study of seawater in connection with the wasting disease of eelgrass, Zostera marina. There are many situations in plant pathology in which water sampling might be helpful, as a study of runoff water in relation to the local dissemination of diseases, the pathological analysis of reservoirs and other water supplies to be used for irrigation, or the investigation of survival of plant pathogens in water, a subject that has received much attention in relation to human medicine. Plant Pathology has only one remotely analogous activity, the chemical analysis of water suspected of containing substances that are injurious to plant growth, such as alkalis, salts, and oil well or

factory wastes, the latter frequently involving lawsuits.

Sampling of air for its microbiological content, initiated by PASTEUR, has been extensively used in studies of dissemination of such diseases as the cereal rusts and downy mildews. It has been helpful in understanding annual cycles of diseases and even in forecasting disease outbreaks. The subject has been reviewed by CHRISTENSEN (1942) and in part by CHESTER (1946b).

As ordinarily conducted, the method consists in exposure of adhesive slides at various altitudes, making use of low or high stationary exposure points or exposing the slides from kites, balloons, or airplanes. The living material adhering to the slides is identified microscopically and sometimes tested for viability by culturing. The results are correlated with prevalence and distribution of the organisms at the ground level and with meteorology and topography.

Each year the annual migration of cereal rusts northward in the Great Plains is studied by analysis of many such "spore traps" in an organized program by the "Rust Prevention Association" in Minneapolis. The data have not been released by bona fide publication; at times they appear to have been helpful in charting the mass movement of rust northward, but in many or most cases they seem to be a less reliable index of rust development than direct appraisal of cereal fields.

SUMMARIZING DISEASE INTENSITY DATA: -- Under this rubric are included two concepts: (1) the reduction of the various manifestations of a disease to a single value, summarizing the total effect of the disease on a plant or small population of plants, and (2) summarizing regional disease intensity data so that a single figure expresses the gross intensity of the disease in a community, county, state, or nation. We will consider these two concepts successively, with the several alternative procedures for each.

When a plant disease has either a totally destructive effect or no effect on a plant or the commercially valuable part of a plant, we have seen that simple percent of infestation is a good measure of disease intensity. In this case, as with the head smuts of cereals, there is no problem in summarizing disease intensity; the summary is simply the average percent of infestation. It is quite another problem when we are dealing with a disease which affects different plants or plant parts in different degrees. To enable the appraiser to summarize disease intensity in these more complex, yet common cases, various devices are used, as outlined in the following sections.

MᶜKINNEY'S "Infection Index" And Its Modifications. -- This device, now widely used, was suggested by MᶜKINNEY in 1923 for summarizing infection of wheat seedlings by root rot disease. Each seedling was classified in one of five classes, from healthy to severely diseased. Each class was given a numerical rating, in this case 0.00, 0.75, 1.00, 2.00, and 3.00 respectively. The "infection rating" then

$$= \frac{\text{Sum of all numerical ratings x 100}}{\text{Total number of inoculated plants x 3}}$$

The factor 3 was used in the formula because this was the rating of the maximal disease category, while the factor 100 converts the final rating to a basis ranging from zero for no disease to 100 where every plant is diseased to the maximal extent.

The MᶜKINNEY index has become widely used for various types of diseases, including cereal seedling diseases and root rots (GREANEY and MACHACEK, 1934, 1935; SALLANS and LEDINGHAM, 1943; HO, 1944), charcoal rot of corn (SEMENIUK, 1944), root rot of peas (P. G. SMITH and WALKER, 1941), root knot (A. L. SMITH, 1941; A. L. SMITH and TAYLOR, 1947), early blight of celery (TOWNSEND and HEUBERGER, 1943), tomato defoliation (HORSFALL and HEUBERGER, 1942a), and onion smudge (HATFIELD et al., 1948).

When the class rating is expressed in percent instead of arbitrary numbers, the disease index may be simplified to the form:

$$\frac{\Sigma \text{ (Class rating (\%) x class frequency)}}{\text{Number of plants or organs examined}}$$

which gives a mean value for disease intensity in percent, as of leaf area involved by disease. This type of disease intensity rating was used by TEHON (1927) and TEHON and STOUT (1930) in their surveys of Illinois cereal and fruit diseases and by BLISS (1933) and P. R. MILLER (1934) for apple rust. KENT et al. (1944) found this method of rating disease intensity for potato scab preferable to two other methods tried, including the one mentioned just below.

A similar modification, called by British workers the "disease severity index" and by RICHARDS the "coefficient of susceptibility", is simply the product of class rating by class fre-

quency, divided by the number of organs or plants examined. This has the possible disadvantage of not being on a 0-100 basis. It is really a simple average of class ratings. It has been used for summarizing intensity of wheat root rot (SALLANS, 1948), alfalfa wilt (RICHARDS, 1937), corn smut and seedling blight (ULLSTRUP et al., 1945), grape, cucumber, and tomato leaf diseases (REICHERT et al., 1942a, b, 1944), and potato scab (KENT et al., 1944). Essentially the same results are obtained if the index of disease severity has the form:

$$\frac{\sum \text{(Class rating x \% plants or organs in class)}}{\text{Maximum class rating}}$$

and this has been used for rating root knot intensity by TAYLOR (1941) and his cooperators.

When the number of plants or organs to be examined is a constant, the index may simply be $\sum$ (class rating x class frequency), as used by CRALLEY and TULLIS (1937) in rating seedling disease in rice and, with slight modification, by RUSSELL and SALLANS (1940) for wheat root rot. An interesting variation has been described under the term "effective leaf index" by LEWIS (1944). This is the reverse of a disease index, obtained by arbitrarily numbering the disease classes with increasing numbers corresponding to decreasing injury.

The widespread use of the McKINNEY index, in original or modified form, testifies to its value. It reduces a disease intensity complex to a single expression that is open to statistical analysis on the basis that "although the estimates are not necessarily in direct linear relation to the amount of fungus present......they are reducible to a linear function of this amount" (MARSH et al., 1937).

Such an expression has many uses, among which are the evaluation of disease in different crop varieties, and of the efficacy of fungicides and other means of disease control. An example of the latter use is seen in the experiments of BONDE and SNYDER (1946) in spraying potatoes, where the effectiveness of any spray treatment, termed the "protective coefficient" was obtained by dividing the "infective indexes" (McKINNEY indexes) of Bordeaux-sprayed plots by the indexes of plots receiving other treatments.

In using the indexes, judgment is needed in assigning arbitrary ratings to the several disease classes. Where possible each class rating should reflect the relative intensity of disease or damage in comparison with ratings of other classes. Class ratings of 0, 1, 2, 3, and 4, for example, would be most appropriate if plants or organs in class "4" had four times the disease intensity of those in class "1", twice as much as those in class "2", etc. If care is used in assigning the class ratings, with absolute disease intensity properly considered, the indices themselves will have absolute, not merely relative, value. A logarithmic series of class ratings might often be preferable to an arithmetic one. If the absolute disease intensities of a class series are 0, 3, 8, 20, and 50, and the classes are assigned arbitrary ratings of 0, 1, 2, 3, 4, then indices of heavily diseased populations will not give a faithful expression of the much greater amount of disease in comparison with populations having lower indices.

The U. S. Department Of Agriculture "Coefficient Of Infection". -- With some diseases, notably rusts, degrees of disease resistance commonly are expressed by differences in type of reaction, as from large, freely sporulating rust pustules through types with smaller pustules to highly resistant reactions in which few or no spores are formed and the site of the infection is marked by a small chlorotic or necrotic spot. At the same time that reaction type varies, rust intensity, or the number of lesions of any type, may also vary. "Coefficients of infection" have been devised in attempts to reduce reaction type and disease intensity to a single value.

In recording the occurrence of rust in the uniform cereal rust nurseries, it is customary to take data on rust intensity, from 0 to 100% according to the modified COBB scale (page 244), and on rust reaction on a scale ranging from 1.0 (highly susceptible) to 0.0 (highly resistant), and multiply the intensity value by the reaction value to obtain the "coefficient of infection".

A very similar procedure was used by GOULDEN and ELDERS in 1926. KOEPPER (1942), working with alfalfa rust, derived a "coefficient of infection" by adding the values for disease intensity, reaction type, and length of incubation period, each on a 0-4 scale. Reference has been made in another connection (page 246) to VAVILOV'S attempt to devise a single cereal rust scale reflecting both rust intensity and reaction.

Rust intensity and rust reaction are usually two independent manifestations of disease. Intensity is a measure of the amount of disease present without necessary reference to host plant reaction. It is the factor of principal interest in studies of loss, epiphytology, and disease control by means other than altering susceptibility in host plants. Reaction type is a measure of host response, of primary interest in attempts to control disease by breeding for disease resistance and in pathogen specialization and variety reaction tests.

It is usually unnecessary and often a mistake to attempt to combine these two measures into a single value. A low "coefficient of infection" could mean either high disease intensity on a highly resistant variety or low intensity on a very susceptible variety. The coefficient can therefore be as misleading in determining variety reactions as it is in appraising the concentration of disease.

TEHON'S Disease Prevalence-Intensity Summations. -- For a number of years TEHON (1927) conducted statewide surveys of the intensity of cereal diseases in Illinois. For those diseases the intensity of which could not be determined by mere counting, the data sheets for each disease included both percent of culms affected and classes of intensity of disease on the individual culms. The average intensity of disease in a field, expressed as percent, was derived through the formula:

$$\frac{\text{Class rating (in \%)} \times \text{culm frequency in each class} \times \text{\% infected culms}}{\text{Total number of culms examined}}$$

In 1930 TEHON and STOUT published a report of their statewide surveys of fruit diseases in Illinois. In this case data were taken on percent of trees affected in a given orchard, percent of organs (fruits, leaves, twigs) infected per tree, and classification of infected organs in percent disease intensity classes, with the aid of diagrammatic scales. The results were summated in a fashion similar to that used for cereals. The methods of summating these data for counties and for the State are given on page 256.

TEHON'S method has the advantage of giving highly precise and accurate disease intensity estimates. Its chief disadvantage, as HORSFALL (1930) has pointed out, is that it is very laborious and time-consuming. Yet this may not be a serious disadvantage, for TEHON has shown that the method can be practically used on a statewide basis, year after year. The formulas for determining disease intensity suggest more effort than is actually required in many cases. With general outbreaks of some diseases, such as cereal rusts or apple scab, prevalence is usually 100%, which can be easily ascertained. Diseases such as smuts can be quickly estimated by simple counting. The time spent in travelling from one field or orchard to another is such a large element in the survey cost that a fairly thorough examination at each stopping point is justified. However, if the method could be simplified without undesirable loss in accuracy, this should be done. One method of simplification which deserves condiseration is the use of correlations. If a constant relationship could be shown, for example, between percent of trees affected, percent of affected organs per tree, and degree of attack per organ, then all of these values would not need to be determined independently.

NAUMOV'S "Average Infection Of Field". -- In 1924 NAUMOV in Russia suggested the procedure for summarizing disease intensity data shown in Table 3. Data are taken or estimates made of the values numbered 1 to 7. There are a number of special cases in which the procedure is simplified. If all plants are infected, $N' = N$ and $A = \frac{Fx}{m}$. In working with large populations of uniform plants as in cereal fields, N, for practical purposes, $= \infty$ and thus N and N' are expressed not in absolute terms but as percentages, N equalling 100%. When all organs on the plant are infected, $X = m$ and $P = F$; if at the same time all plants in the field are infected (a common case with cereal rusts and many other field-crop diseases), $A = F$, i.e., the average infestation of the field equals the average infection of the organs of an average plant. For diseases in which d is unity or total (e.g., head smuts), d can be omiited, and $P = x/m$. For ergot, d, the degree of infection of the different spikelets, is constant and can be omitted; here however, an additional step in the observations is required, viz., determination of the total number of spikelets per head and the average number of these which are infected.

In principle the scheme of NAUMOV resembles that of TEHON, and the logical character of both, proceeding through degrees of infection of organs, plants, and populations, commends them to the thoughtful consideration of those who are interested in more accurate appraisal of disease intensities on a field, or larger area, basis.

DUCOMET and FOËX' Summary Value For Disease Intensity. -- In France, DUCOMET and FOËX (1925, 1928) have proposed a very elaborate procedure for reducing rust infection of a cereal plant to a single absolute value. Using a descriptive scale of 7 stages, from "trace" to "enormous", each organ of the plant is scored separately, including head (glumes, awns, rachis, grain), each internode, numbered from above downward, and each leaf and leaf sheath, which are numbered, with separate records of rust intensity on proximal, medial, and distal parts of each leaf. Each part scored is given a coefficient to weight the readings according to the importance attached to each, and the overall rust intensity is then calculated by use of prepared tables. At each examination six scorings per head and three each per leaf and stem are recommended, and it is advised that examinations be made at boot, heading, and post-blossoming stages, and 3-4

Table 3. NAUMOV'S (1924) method for summarizing disease intensity data, slightly revised.

1. Degree of disease per organ = d	Average infection of organs = $\frac{d_1 + d_2 + \ldots\ldots\ldots\ldots d_x}{x} = F$		
2. No. infected organs per plant = x			
3. Total no. organs per plant = m	Average infection of plant = $\frac{Fx}{m} = P$		
4. No. infected plants per field = N'		Average infestation of field = $\frac{PN'}{N} = A$	
5. Total no. plants per field = N			
6. No. infested fields in region = Q'			Average infestation of region = $\frac{AQ'}{Q}$
7. Total no. fields in region = Q			

times thereafter.

The method of DUCOMET and FOEX, which has also been used by RIVIER (1932), appears to be theoretically sound. It does reduce rust infection of the entire plant to a single, defensible value. Yet it is so complex and time-consuming that more accuracy may be lost through restriction of the number of examinations which can be made than is gained by the greater detail of each examination. Doubtless there are correlations between rust intensities on most of the organs or tissues which are separately scored, and if this is true it is unnecessary to score all of them in ordinary disease appraisal practice.

Summarizing Disease Intensities Of Regions. -- Up to this point we have been principally concerned with disease intensities on individual plants, plots, or single fields. In disease survey practice it is usually the objective to extend estimates to embrace larger regional units, such as counties, states, provinces, or nations.

With minor variations the same method is used by most workers. This, essentially, is a McKINNEY disease severity index applied to large numbers of single plots, and has the general form:

$$\frac{\Sigma \text{ (field rating class x acreage in class)}}{\text{Total acreage}}$$

The field ratings are usually classified in a series of grades, from 0 to 100 percent disease intensity; but arbitrary grade values could also be used. TEHON (1927) and TEHON and STOUT (1930) have followed the practice of determining the mean disease intensities for counties by an analogous process, and then by weighting the county values for acreages of the crops concerned, have derived mean State disease intensities.

Reference to Table 3 shows that NAUMOV has used a similar device, based, however, on the number of fields rather than the acreage, as also seen in the works of WALKER and HARE (1943) and SAVULESCU and RAYSS (1935). This would suffice if the fields sampled are of sizes typical for the region, but might lead to error if the sample fields are not of representative size. Since county and State acreage figures are readily available from census data, the acreage basis can be easily and preferably used.

In the United States each State is divided into several crop-reporting districts for purposes of agricultural economics, and in Canada there are similar districts which do not correspond to the Provinces. Meteorological, yield, acreage, and other useful data are available by crop-reporting districts. Since each district is more uniform agriculturally than are political divisions, there

will frequently be advantages, in planning surveys and summarizing disease intensity and loss data, in using the crop-reporting district as the basic geographic unit.

Plant Disease Intensity Maps. -- Disease intensity data may be usefully summarized in the form of maps. This is one aspect of the value of disease hazard maps, which has already been discussed (page 203). Most such maps, of which many have been published, show only disease occurrence, without information on the degree or intensity of a disease in various regions. Some disease intensity maps are available. Examples are the Texas root rot map of TAUBENHAUS and EZEKIEL (1931, Fig. 1) and the chestnut blight map given by BAXTER (1943, Fig. 38). In the volumes of the *Plant Disease Reporter* are occasionally found maps in which disease intensities are indicated for various States or for counties within a State, such as that of wheat leaf rust in Oklahoma prepared by CHESTER and PRESTON (1948).

WEIR (1918) and BAXTER (1943) have both pointed out the importance of disease maps in forest pathology, and the one presented by BAXTER in his Fig. 39 is a good illustration of a map showing the distribution of several diseases and types of injury although different disease intensities are not represented.

Punch-Card Systems. -- A device for summarizing disease survey data that has received very little attention from plant pathologists is the use of punch-card systems. Their probable usefulness for this purpose is indicated by their established value in organizing economic and other survey data obtained through use of the Iowa Master Sample (*cf.* page 268). They are much more than a file, since if disease intensity data are properly recorded on punch cards it is possible to summarize the data from any of numerous standpoints, by crop, region, year, disease type, etc., very rapidly. It would appear highly desirable that this versatile method of recording data be fully explored to determine its potentialities for plant disease survey purposes.

Chapter V

THE METHODS OF PLANT DISEASE SURVEYING

To be useful for the several purposes discussed in Chapter I, data on plant disease destructiveness cannot be limited to isolated cases, however dramatic these may be. For effective action on an area basis we must have representative cross-sections of the disease hazards involving whole counties, states, or nations. Such data can best be obtained by plant disease surveys, -- planned and uniform samplings throughout the areas involved.

Of late the term "survey" has fallen into some disrepute as a result of a few real or fancied cases of the misuse of public funds in trivial fact-finding. Protagonists of "action programs" sometimes criticize surveying because, while it provides facts, it does nothing to alter unsatisfactory conditions; it eliminates no slums, prevents no crime, sprays no plants. Such an attitude is short-sighted and may often lead to waste from misguided "action programs" with objectives determined by the spectacular character of minor problems. Yet it is an attitude influencing the success of plant disease appraisal, one that must be considered and overcome by demonstration of the practical value of surveys in revealing the absolute and relative magnitudes of plant disease hazards. No survey is perfect; all are subject to faults that arise from the complexity of the problem of surveying, inadequate financing, and human limitations. Yet, despite these imperfections, they have been of inestimable value, and this will increase as survey techniques improve.

ORGANIZATION AND PLANNING OF A SURVEY: -- Plant disease surveys can be thoroughly justified if they are wisely planned and if their results and applications to "action programs" are made clear. Several elements are involved in the judicious planning and execution of plant disease surveys: (a) they should have definite objectives; (b) their objectives should be clearly related to useful applications of the results; (c) their methods should be adapted to the specific objectives; and (d) they should be sufficiently thorough to permit reliable conclusions but no more so, in the interest of economy, than is necessary for such conclusions.

That plant disease surveys should have definite objectives has been stressed by a number of authorities (HAENSELER, 1944; CHUPP, 1945; P. R. MILLER, 1946). HAENSELER has justly criticized what he calls the "shotgun" type of survey in which the surveyor is merely directed to "look around and see what he can see". Such surveys produce such incomplete data that they may hardly be useful. That such surveys have been made probably indicates atavism, in plant pathologists, to the point of view of taxonomic botanists whose forays often have no objective other than to collect any and all interesting plants which may be encountered.

At the same time that each survey should have a specific objective, the surveyor should not be blind to unusual, accidentally encountered disease situations, outside the scope of his survey. The greatest item in the cost of surveying is the expense of travel and subsistence of the surveyor, and the time actually spent in the field may be small in relation to the total travel time. To increase the amount of time spent in actual observation may add little to the total cost of a survey, while providing by-products, in the form of data not originally specified in the survey objective, that contribute substantially to the justification and value of the survey. It goes without saying that such adjunct observations should not be permitted to interfere with the main purpose of the survey. It is sometimes said that surveys should be limited to the more important diseases (<u>e.g.</u>, BÖNING, 1936). This is quite illogical; without surveys and loss appraisal how can we know which diseases are more important?

The method, intensity, and scope of a plant disease survey will vary with its objectives. At times it may be desirable to study a limited number of fields very thoroughly, while in other cases it may be more useful to have less precise data from many random samples scattered over a broad area. Sometimes the two methods are combined, as in Dutch elm disease scouting, where a thorough, systematic survey of all elm trees in known infested areas has been supplemented by autogyro scouting along rivers and railroad lines over a great range outside the infested area, to locate other isolated infestations.

The work of the U. S. Bureau of Entomology and Plant Quarantine embraces several types of surveys, with different objectives and procedures (GADDIS, 1947; see also page 277). Most frequent are <u>surveys for usual regulatory purposes</u>, for locating and delimiting unknown infestations and determining the spread of new ones. These furnish the "blue prints" for regulatory action. <u>Unusual or special surveys</u> are to obtain information on specific pests, to determine the need for new or continued quarantines. They employ the method of spot inspections, with study of the ecology of the pests, and are not intended to delimit areas of infestation. <u>Surveys for new pests</u> are conducted to determine the distribution and behavior of recently introduced or little-known pests, and emphasize study of the spread, reproduction, natural control, and economic

importance of these. Their chief objective is to determine the potential destructiveness of new pests before these become widespread. The emergency wartime surveys for detecting the introduction, by chance or malice, of new insects and diseases, illustrate general surveys for possible unknown pests. These also have important peacetime uses. Surveys for non-regulatory control purposes are for the purpose of planning regional or national volunteer control programs, such as those directed at control of grasshoppers and chinch bugs. Finally, the Bureau of Entomology and Plant Quarantine conducts surveys to determine pesticide supplies and requirements, so that limited supplies of pesticides can be directed to areas of greatest need. These have critical importance in time of war.

When several surveys are made for the same purposes, in different areas or seasons, it is highly desirable that uniform methods be used so that reliable comparisons and summaries of the survey data can be made.

The degree of thoroughness that is desirable, yet economical, depends on the objective. In some cases data on presence or absence of a disease are sufficient; in others it may be necessary to determine, with greater or less accuracy, the concentration of disease present. Some diseases, such as the cereal rusts, affect great acreages rather uniformly, and here fewer samplings are needed than with diseases that are more dependent on local environmental or agricultural conditions for their occurrence. General-utility surveys are broad, less intensive and less exact than special-interest or special-purpose surveys, such as those designed to aid plant disease research.

A good illustration of a well-planned intensive survey is that of F. R. JONES and LINFORD (1925) for pea diseases in Wisconsin. The survey involved 688 fields, each of which was visited two or three times, and data were taken on location, owner, pea variety, growth stage, date of planting, soil type, cropping history, and occurrence of 13 diseases, aphids, and root nodulation.

As an example of a well organized survey of the extensive type, we have that of VESTAL, on the use of disease-resistant oat varieties in Iowa in 1944. His problem was to obtain a uniform sample, representative of all farms in the State, and actually involved 74 of the 99 counties in Iowa. A tracing was made of the map of each county, numbering all sections along a main road through the county. A minimum of two sections from each county were chosen by selecting section numbers at random, and of these, quarter sections were selected at random. The number of sections selected was proportionate to the total number of sections in the county. Sampling of 149 farms in this fashion showed, with other data, that 13.75% of the land on these farms was planted with oats. This compares with 13.2% of land in oats estimated in the Iowa Assessors Annual Farm Census, based on data from several thousand farms, showing that VESTAL'S sample was reasonably representative. Using this method one man was able to sample slightly more than four counties per day, and a survey of the entire State, by this method, would consume only about 20 days.

P. R. MILLER's (1935) survey of fruit and vegetable losses in market and kitchen, in Knoxville, Tennessee, may be mentioned as an example of a survey involving use of many untrained collaborators. The first step was to determine the channels of flow of fresh produce in Knoxville by interviewing dealers. Data were gathered on the times and places of car unloadings, the time before distribution of the produce, and the quantities distributed to retail dealers. The distributors' losses were determined in two ways. Managers were asked to keep records of their purchases and lay aside spoiled produce for inspection by the surveyor, and the latter also made random samples of produce as it was being sorted in the warehouse. Losses to the ultimate consumer were determined by a house-to-house survey, facilitated by a preliminary appeal to housewives through the press, radio, and garden clubs. Each interested consumer was given a chart illustrating and describing the principal fruit and vegetable diseases, and a record sheet for recording losses, and data were also taken on the housewife's source of produce, frequency of purchase, methods of selection and storage, and other pertinent information. A final estimate of total loss was obtained by combining distributors' and consumers' losses.

The advantage of using lay cooperators in a survey, as MILLER has done, is the large volume of data that can be obtained at limited expense. Its disadvantages are the lower reliability of such data compared with those which are gathered by a trained surveyor, and, in this case, probably some error due to the fact that willing cooperators are likely to be those who are more careful in preventing spoilage of produce. These disadvantages were minimized in MILLER'S survey by efforts to secure uniform data through use of standard data sheets and an identification chart of types of spoilage, and by control samplings made by the surveyor himself, which gave an index of the reliability of the data from cooperators.

PROCEDURE OF SAMPLING: -- At the outset we must distinguish two types of sampling, crop (or commodity) sampling and opinion sampling. The former consists of appraising a part of a crop, before or after harvest, and considering the findings as evidence of the quantity and quality

of the whole. Such procedure assumes training in the accurate appraisal of samples. The sample itself may consist of a few plants in a field, a few fields in a county, a few counties in a State, or a few States in a region, or a combination of these.

In the case of opinion sampling, which in agriculture is illustrated by the Crop Reporting Service (page 272), the sample is a part of the human population, and the data obtained consist of the opinions of the people in the sample regarding any question asked them. The reliability of the findings varies with the degree of accuracy with which individuals can appraise the matter in question. In plant pathology we could expect that an opinion poll of wheat farmers who are asked questions regarding smut dockage in the price received for their wheat would be fairly accurate, while the same farmers, lacking training in disease appraisal, might be very poor sources of information on field losses from smut, rust, or root rot.

Assuming some training of lay observers in plant disease appraisal, there is a third type of sampling in which the useful features of opinion and crop sampling are combined. This is illustrated by P. R. MILLER'S (1935) survey of market losses in fruits and vegetables, in which lay correspondents, dealers and housewives, were given sufficient instruction so that they could provide reasonably accurate reports, based on counts and measurements, of the spoilage in perishable produce.

Several methods of opinion sampling are recognized (SABROSKY, 1946) and these have counterparts in crop sampling. Random sampling is illustrated by obtaining information from every n^{th} person named in an alphabetical list or by appraising a crop field at every n^{th} mile indicated on an automobile speedometer. Area sampling involves questioning all people or examining all fields on random areas, and is economical of the surveyor's time. Stratified sampling of opinion consists of getting definite proportions of various types of persons in a sample when the fraction of each type in the total population is known. This is commonly used in public opinion polls which are broken down by sex, profession, race, or political party. An example of stratified crop sampling would be to sample ten wheat fields for each one barley field if it were known that the wheat acreage was ten times the barley acreage. If desired, a greater sample than corresponds to the fraction of the population may be taken for certain items, with the results weighted to correct for the proportion in the population. Thus, if a certain crop disease presents an unusual hazard (e.g., Victoria blight of oats) the surveyor might take a disproportionately large number of oat samples. Finally there is purposive sampling in which all or nearly all of the population having certain narrowly specified characteristics is sampled, as would be the case in sampling all stone fruit nurseries for virus diseases, or in disease appraisal of the fields of all growers of certified seed potatoes in a State.

In studies on comparative yields and other properties of crop varieties or crops subjected to different treatments, much attention has been given to methods of sampling, and many of the principles of sampling that have been developed and used for various agronomic and horticultural purposes have interest and usefulness in plant disease appraisal. While this discussion is from the plant pathological viewpoint, it should be regarded as but one of many applications of general sampling practice.

TIME AND NUMBER OF CROP SAMPLES: -- Of the factors which determine the time, number, size, and type of samples, two are outstanding and diametrically opposed, -- reliability and economy. Neither can be increased except at the expense of the other, and the preferred schedule of sampling must be a compromise which avoids the expense of increasing accuracy beyond the least degree that will give a practical, reasonably satisfactory answer to the problem at hand. This principle of the "minimal reliable sample" is discussed on page 264.

The desirable number of samples to be taken, whether it be quadrats in a field or fields in a region, varies with crop, disease, and environment, and the pathological situation, with the factors influencing disease variability, must be studied in order to determine the most practical sampling procedure. Equal reliability can be obtained from fewer samples if few varieties of a crop are grown, if the disease is one which affects large areas uniformly, and if the survey area shows relative uniformity in soil, climate, and cultural practices. Airborne diseases are usually more uniformly distributed and require fewer samples for equal reliability than soilborne diseases As contrasting cases, Fusarium wilts, soilborne diseases of irregular distribution in a field and from one field to another, that are frequently controlled by use of resistant varieties, would require far more samples, for equal reliability, than wheat leaf rust in the Great Plains, where the disease frequently is fairly uniform in any given field and over a great region.

When an area is non-uniform it may be subdivided into relatively uniform subareas, each of which is sampled separately. This was done, for example, by MACHACEK (1943) who made use of six soil type zones in sampling wheat root rot in Manitoba. When a principal objective of samp-

ling is to compare disease intensity and loss from one year to another, variability can be reduced and reliability increased by use of standard observation fields each of which is planted with the same crop and variety and otherwise similarly treated from one year to another. This has been the custom in the annual samplings of wheat fields as a basis for leaf rust forecasts.

Other factors being equal it is usually good practice to have the number of samples taken in each of a series of fields proportionate to the acreages of the fields, and to apply the same principle to the number of fields sampled per region. If the disease is uniform in any given field, regardless of size, the same result may be more economically obtained by taking a minimal, constant number of samples from each field and weighting the value attached to each sample according to the size of the field.

The most suitable time for sampling disease intensity is usually the peak of disease attack. This varies widely with different diseases in a single crop, often necessitating several samplings of the same crop if a complete record of disease attack on that crop is desired. With wheat, for example, speckled leaf blotch (Septoria tritici) should usually be sampled when the plants are in the rosette to jointing stages, loose smut (Ustilago tritici) at blossoming time, leaf rust in the post-blossoming to stiff-dough stage before the leaves have died, and stem rust at submaturity of the crop, while bunt may best be sampled in sheaves after harvest, and root rots may require several samplings throughout the entire life of the wheat plant.

This fact accounts for some of the discrepancies or unbalanced emphases on the prevalence and importance of crop diseases, that are based on a single crop inspection. Agronomists and crop scouts tend to concentrate attention on cereal crops as they approach maturity. This often results in an overemphasis on those diseases which are most prominent at this period, overlooking the early-season diseases such as speckled leaf blotch and loose smut of wheat, cereal mosaics, and barley stripe.

In disease intensity appraisal for the purpose of studying the tempo of disease development, several successive samplings of the same plantings are required. This has particular importance in relation to forecasting the destructiveness of diseases such as cereal rusts or potato late blight. More than one sampling will also be required if a given disease reaches its peak of destructiveness on different crop varieties or fields at different times. Sampling for appraising loss from plant diseases obviously coincides in time with the normal harvesting and post-harvest handling practices.

Wherever possible, post-harvest sampling for disease intensity has the advantages that it may be done at any convenient time after the rush of preharvest work, in a uniform and objective manner, in the laboratory where the work is facilitated by ready access to scientific instruments and unhampered by wind or wet weather. By using the soaking method described by POPP (1947), for example, bunt in harvested wheat sheaves can be much more accurately, rapidly, and conveniently counted than in the field before harvest. Loose smut may be more accurately counted in the same operation than in the field after the smut spores have blown away and the short, naked rachises are inconspicuous. Stem rust may be easily appraised after harvest, and there are many other diseases in the same category.

In such cases one precaution is necessary, namely that the harvested sample is fully characteristic of the disease as it occurred in the field. A serious error arises, for example, if the percent of bunt balls in threshed wheat is taken as the percent of field occurrence and loss, since many of the bunt balls are removed from the grain in the harvest operation. HASKELL and BOERNER (1931) have shown that fields with 6.6% smut occurrence and loss produce grain which, after threshing, contains only 2 to 5 bunt balls per 50 grams of grain.

SIZE AND TYPE OF CROP SAMPLES: -- The choice of size of individual samples, like that of the number of samples, must be a compromise between reliability and economy, since any increase of sample size usually increases both its reliability and its cost. The optimal size of sample also varies with crop, disease, environment, number of samples taken, skill and bias of the appraiser, accuracy of the appraisal method, and other factors, which requires a thorough study of the disease situation and its variability before one can determine the optimal size of sample.

Sample size has primary importance in studies of crop yields and much attention has been given to this by agricultural workers. Their findings have many applications in the appraisal of plant diseases. In the Statistical Laboratory of Iowa State College there is an important research program on the study of the effect of size of primary sampling units on statistical efficiency in relation to crop yield determinations. The papers by COCHRAN et al. (1945), HOMEYER and BLACK (1946), and HOUSEMAN et al. (1946) illustrate this study and describe optimal-sized samples of corn, small grains, soybeans, and hemp.

With crops that are closely planted or planted broadcast the approved sample is usually a quadrat, several square feet in area. A standard wire frame that is square, rectangular, U-shaped, or round, is often used to assure that all samples will be of the same size. This is placed in random locations and all plants falling within the frame constitute the sample. The quadrat sizes recommended for yield or disease determinations of various crops include 3 x 3 feet for oats (HOMEYER and BLACK, 1946; COCHRAN et al., 1945), 2 x 2 feet for soybeans (HOUSEMAN et al., 1946), 32 x 32 inches for corn (KIESSELBACH, 1918), 3 x 3 feet for alfalfa and sweet clover (WILLARD, 1931), 3.3 x 3.3 feet for cereal smuts in broadcast fields, and 3 x 3 feet for ergot in rye (U. S. Department of Agriculture).

While the quadrats should be small for labor economy, there is danger of serious error if they are much below such sizes as those mentioned above. COCHRAN et al. (1945) and HOMEYER and BLACK (1946) have found that with oats and wheat 2 x 2- or 2.178 x 2-foot quadrats regularly lead to overestimates of yield due to observer's bias, which is not important in 3 x 3-foot quadrats. This bias results from tendency to include within the quadrat plants at the edges, of doubtful position, and the smaller the quadrat the greater the ratio of periphery to enclosed area.

Statisticians have given considerable attention to quadrat size in India. MAHALANOBIS (1946), working with jute, wheat, and rice, considers that bias error is negligible in plots 40 to 50 sq. ft. in size or larger, although in plots smaller than this yields are overestimated by 3 to 15%. SUKHATMA (1947) goes still farther, citing the finding by PANSE that even a plot of 218 sq. ft. results in overestimation of yield, and favoring plots of 1/80 acre (545 sq. ft.) which have been adopted by the Indian Council for Agricultural Research in its yield surveys. While plots of such size would be practical for gross yield determinations, the small replicated quadrats recommended by American workers would be preferable for most work with diseases of field crops.

Another type of sample in common use with row crops is a measured length of row, in random locations. MACHACEK (1943) used replicated meter-length row segments, ROBERTSON et al. (1942) used 5-foot segments for wheat root rot, and NELSON and LEWIS (1937) have favored samples of 30 consecutive plants in the row in studying celery leaf blight. A similar procedure is common in sampling various crops for seedling disease and in study of diseases of such crops as cotton, corn, and sorghums.

Sometimes other practical considerations dictate the type of sample. With small grains, for instance, strips cut through the centers of plots with a power mower, while giving a greater sampling error than 2.178 x 2-foot quadrats, are preferred because the loss in accuracy is more than compensated for by labor saving in harvesting (HOMEYER and BLACK, 1946). The ideal sample for field crops, in the opinion of SUKHATMA (1947), is a circle containing 218 sq. ft., but such a plot is quite impractical to harvest.

Methods such as the foregoing are much preferable to the loose general directions for sampling which are sometimes given. The "Cereal Disease Field Notebook" of the U. S. Department of Agriculture, though giving specific directions in some cases, in others instructs the observer to make "counts of entire plants in different parts of the field", to "gather a number of leaves from the row or plot at random", or to make "counts of representative areas in the field." As might be expected, the data obtained by different observers, following these loose instructions, vary widely in reliability.

When the sample consists of a collection of certain organs of plants, sampling directions must specify how those organs are to be chosen, whether at random or in some other specified fashion. Cereal leaf rust readings vary with observers, some of whom make collections of leaves of all ages while others select leaves of a certain rank on the plant, e.g., the flag leaf, and still others select the rustiest leaves or the oldest leaves that still remain green. In making readings of the intensity of speckled leaf blotch on wheat the writer has obtained the most consistent results by limiting the sample to the 2nd, 3rd, or 4th leaf from the uppermost one on jointed wheat, thus obtaining a uniform sample of leaves of approximately the same age and duration of exposure to the disease. The particular rank of leaves to be used is determined by preliminary observation of the amount and location of disease present. Methods of sampling to determine varietal reaction to disease or response of plants to disease-control treatments may often be used for the purpose of disease intensity-loss appraisal.

It sometimes happens that of two methods of sampling, of equal reliability, one is more rapid and economical than the other. This is illustrated in a comparison made by TOWNSEND and HEUBERGER (1943) of two methods of determining intensity of early blight in celery. In the "leaf-classification method" all leaves from 10 random plants were picked, graded, and scored, to give the percent of leaf involvement by blight. With the "plot-scoring method" each plot was assigned one of 10 grades of disease infestation and these were converted into percent leaf involvement by multiplying the grades by a constant. The latter method took only 1/24 as much time as the for-

mer and gave results that were highly correlated (r = +0.887 at the 1% point) with the more laborious method. This case brings out the important saving in the appraisal expense that can be realized from a comparative study of appraisal methods before adopting any one method.

The certification of seed potatoes involves indexing foundation stocks in the South. The cost of this is so high that the smallest reliable sample must be used. In other steps in potato seed production and inspection the same problem occurs. FOLSOM in 1942 published a table showing the number of tubers that must be examined in stocks containing 2, 3, 4, ...10% disease to give the percent of disease present with a reliability of $\pm$ 0.5, 1, 2, 3, 4, or 5% at 30:1 odds. The table indicates that if there is 3% disease present, 2735 tubers must be examined to be sure the reading is significantly between 2% and 4% at these odds, which are considered adequate in this case.

FERNOW in an important contribution in 1944 developed this principle further. He considers that 10:1 odds are sufficient, since an error affects only a few persons and one year's work. FOLSOM has assumed that the question involves whether an observation is either greater or less than the true mean, but in actual practice, FERNOW points out, the question is only whether the observed value is significantly less than the mean. The ideal frequency distribution curves for small samples from stocks with small percentages of disease can be determined by expanding $(p + q)^n$ where p = the proportion of stock healthy, q = the proportion diseased, and n = the number of tubers in the sample. This has been done in Table 4.

Table 4. Minimum and maximum disease percentages likely to be found in samples of indicated size when taken from stocks showing indicated disease percentages. Odds 10:1 against either less or more; 4.5:1 against both. (From FERNOW, 1944).

Size of sample	Percent disease present in stock: 1	2	3	4	5	6	8	10	15
50	0-2	0-4	0-6	0-8	2-10	2-10	4-14	4-16	8-22
100	0-2	0-4	1-5	2-7	2-8	3-9	5-11	6-14	10-20
200	0-2	1-3.5	1.5-4.5	2.5-6	3-7	4-8	5.5-10.5	7-13	11.5-18.5
400	0.5-1.8	1.2-3	2-4	2.8-5.2	3.5-6.5	4.5-7.5	6.2-9.8	8-12	12.5-17.5
800	0.5-1.5	1.4-2.6	2.2-3.8	3.1-4.9	4-6	4.6-7.4	6.8-9.2	8.5-11.5	13.2-16.8
1600	0.6-1.3	1.5-2.5	2.4-3.6	3.3-4.7	4.2-5.8	5.2-6.8	7.1-8.9	8.9-11.1	13.7-16.3

Whereas FOLSOM, with arbitrary 30:1 odds, concluded that 2735 tubers of a stock with 3% disease must be examined in order to get a value within 1% accuracy, FERNOW'S table, with 10:1 odds, which he considers are justified by the situation, shows that a 400-tuber sample would be adequate, and since in practice it is usually impossible to use samples even of this size, he concludes that we must be satisfied with a 2% error instead of 1%, which, in this case, would be obtained with a 100-tuber sample.

This case has been described because it illustrates the possibilities in predetermining sample size with statistical accuracy, provided the appraiser is familiar with his material and can decide on the degree of error which is tolerable and justified. The method has many other possible applications in disease appraisal.

In crop sampling for disease, just as in sampling for yield or other characteristics, replicated samples are regularly used, the number of replications commonly ranging from 5 to 10. The principles governing the use and number of replications are those commonly found in textbooks on statistical methods, the desired number of replications necessarily increasing with the variability in distribution of the disease. In sampling commercial fields the replications are taken at random, using such techniques as those described below, but in experiments designed to measure disease intensity and loss use can and should be made of replicated planting plans designed to give results most suitable for statistical analysis, in which case the samples are systematically taken from the replicates.

The British committee on disease measurement, after careful study of sampling methods, has issued recommendations on sampling methods for a number of leading plant diseases (W. C. MOORE, 1943; Anon., 1943). Some of these are given here to illustrate well-considered

sampling practice.

British sampling recommendations: For virus diseases of potato and sugar beet: If there is less than 1% disease present, estimate 1 diseased plant in a 12-yd. radius (potato) or a 7-yd. radius (beet) as 0-0.1%, and 1 diseased potato plant in a 4-yd. radius or 1 beet in a 2-yd. radius as 0.1-1.0%; if there is more than 1% disease take 5 random samples of 100 plants each on diagonal traverses for general surveying or 10 samples for special purposes (certification). For cereal smuts, take-all, eyespot, and brown root rot causing white heads: If less than 1% disease is present, 1 head in 50 sq. yd. = 0-0.01%, less than 2 heads per sq. yd. = 0.01-1.0%, and 2 or more heads per sq. yd. = 1.0%; for higher disease percentages make counts of 10 random grab samples, each of 20+ headed tillers, on diagonal traverses. For apple scab: Sample 10- to 15-year-old trees of specified varieties, examining 25-50 well-distributed trees per variety; grade visually by walking slowly around the tree, recording the individual grades and the average, but if the first 5 trees show no more than 1% scabbed leaves further grading is unnecessary; a grading scale is furnished (W. C. MOORE, 1943).

PRINCIPLE OF THE MINIMAL RELIABLE SAMPLE: -- In the interest of economy, a sample or sample-group must be as small as possible while still giving results with no more than the greatest allowable tolerance for error. The factors influencing the size of the minimal reliable sample are the allowable error and the causes of error (variability of population sampled, and non-representative sampling due to bias or imperfect techniques). The allowable error should be predetermined; it is influenced by the purpose of sampling and cost considerations. Sampling to obtain data for propaganda purposes, for example, would have a higher allowable error than sampling for regulatory purposes.

Earlier in this chapter reference was made to the considerable error that results when samples of too small size are used, and to the work of FOLSOM and FERNOW in determining the sizes of potato samples corresponding to given percentages of allowable error. It should be borne in mind that sample size alone is no proof of accuracy; if a sample is non-representative, increasing its size makes it worse.

The British survey workers have made a valuable and exemplary contribution to the techniques of plant disease surveying in their study of minimal reliable sample size, including both the number and size of samples to be taken from a single field and the number of fields to be assayed. In studies of potato leafroll, blackleg, storage blight, and onion downy mildew it was found, for example, that appraisal of 10 fields gave disease values closely approaching those obtained by examining up to 157 fields. In adding more and more samples a point is reached at which additional samples do not seriously affect the average, and from this point, which can readily be determined by statistical comparison of different-sized samples, practically optimal sample size can be ascertained.

In a study of soybean yield sampling, HOUSEMAN et al. (1946) illustrate the derivation of the minimal reliable sample. Here the variation of the average sample = $(t_1 + kt_2)\ (A + \frac{B}{k})$ where t_1 is the average time spent in getting to and from the sampling units, exclusive of travel time, t_2 is the time spent in gathering the sample, k is the number of square feet in the sample, A is the variance attributable to fields, B is the variance per sq. ft. within the sample, $(t_1 + kt_2)$ is the total time spent in sampling, and $(A + \frac{B}{k})$ is the total variance between fields. In the soybean study, $\frac{t_1}{t_2}$ equalled 6, and if the value of k that minimizes sampling variance to a satisfactory amount = $\frac{t_1 B}{t_2 A}$, in this case the optimal sample size was 7.1 sq. ft. or approximately 1/6000 acre.

The same principle is followed in forest appraisal, as brought out by LEXEN (1947). Here the coefficient of variation is liberally estimated at 80%. The number of trees to be sampled is obtained from the formula:

$$\frac{(\text{Coefficient of variation})^2}{(\text{Acceptable sampling error})^2}$$

If 2.5% is considered an acceptable error, $\frac{80^2}{2.5^2}$ or 1025 trees should be examined. This is in fairly good agreement with HEPTING'S estimate of 3% error for a 1000-tree sample or 5% for 500 trees in sampling for butt rot cull, and with the sample-size table published by ZILLGITT and GEVORKIANTZ (1948) in which sampling error ranges from 9.6% for a 160-tree sample of 800

trees to 2.1% for a 4000-tree sample of 80,000 trees.

The economy in determining the optimal sample size is brought out in CROWTHER'S (1941) study of disease and other yield factors in cotton. Here it was shown that the results from a single experimental plot were of the same general order as those from a surrounding area of 25,000 acres. The same economy is seen in VESTAL'S (1944) study of Iowa oats plantings, in which a sample of 149 farms showed that 13.85% of the land on these farms was planted with oats, as compared with the figure of 13.2% from the Iowa farm census based on sampling several thousand farms.

MANNER OF OBTAINING RANDOM SAMPLES: -- Plant diseases and their effects are often quite irregularly distributed through a field or from one field to another. Diseases also often show the well-known border effect, with a greater or less disease intensity at the margin of a plot, field, or region. Disease appraisers, unless they have some means of ruling out the personal factor, commonly tend to select samples that are not truly representative, from more heavily diseased areas or the "best" of a field or fields of a region. To avoid this error, ingenious methods of obtaining random samples have been devised, and comparable methods should form part of regular sampling practice.

To avoid border effect in fields, sampling directions frequently mention taking no samples within a specified distance of the field margin, e.g., 10 or more paces or 1/5 the diameter of the field. Nor should all the samples be gathered in one region of the field. This can be avoided by directions to take samples along traverses across the field, preferably two diagonal traverses in opposite directions, completely crossing the field if it is not too large. This method is regularly followed in British surveying. In forest surveying it is sometimes the practice to sample every tree or every n^{th} tree in a compass line. The latter principle is sometimes used in sampling row crops, the observer examining every n^{th} plant in the row or the plants in every n^{th} row, in accordance with the sample size required. In other cases the appraiser walks a specified number of paces, taking his sample at the point marked by his foot at the completion of the n^{th} pace. As an alternative, the distance between samples may be specified in feet and measured. More representative samples are usually obtained if the traverse is across rows, rather than along them.

The British workers often make use of "grab samples" in which the eyes are closed and the sample is the branch or cluster of stems or leaves struck by the hand. If the sample is a quadrat, defined by a wire loop, objective samples may be obtained by throwing the loop a considerable distance from the observer, preferably in a random direction obtained when the observer loses sense of direction by turning around several times with eyes closed. This method is not recommended when two observers are working in close proximity.

In small plot experiments with cereals where 3-row plots are used, it is customary to take the sample from the center row to avoid plot border effect. This is a limitation on the pathologist who makes use of routine yield experiments for his disease measurement tests, since disturbing the center row in these experiments may introduce errors in yield determinations. In such cases it is better that disease measurement experiments be conducted with this as their primary purpose.

The surveyor's ingenuity will often suggest unique, useful methods of eliminating personal bias. In sampling forest trees, for example, LEXEN (1947) used a pocketful of marbles of which one was red, four black, and 45 white. At each tree encountered, he drew out a marble at random; if white, the tree was merely counted, if black the diameter was measured and the height estimated, while if the red marble was drawn the tree was blazed, indicating that its volume and cull would be measured after felling.

In selecting fields for sampling while driving along a highway, an objective method is to use the cropmeter, which measures roadside frontage of the crop(s) being surveyed, with stops for sampling at predetermined intervals of distance indicated by the meter. When the problem is one of selecting, for sampling, farms scattered over a county, a good procedure is to use a map tracing on which all sections of a county are numbered consecutively, and the sample is determined by drawing random numbers, using numbered paper clips or other tokens. The same method is used to determine which quarter-sections of a selected section, or which counties of a State, will be sampled.

Objective instruments are available for sampling some types of harvested produce. Best known of these is the compartment grain trier, a long tube with ten openings at intervals, leading to separate compartments, all of which may be opened and closed simultaneously by twisting a second tube with similarly placed holes, which surrounds the first. With this instrument, in one manual operation, ten samples may be obtained, taken at different depths in the grain bulk. Further objectivity is obtained by using a standard sample mixer, which homogenizes the sample,

so that a smaller subsample becomes representative of the larger one. For sampling grain as it runs out of a spout, as in loading ships, a "pelican" is used, a long-handled scoop shaped like a pelican's bill.

As a final example of techniques for obtaining random samples, the following illustrates a very detailed and carefully considered method, used by HOUSEMAN et al. (1946) for sampling soybeans. On a route along well-distributed roads a stop was made each time the cropmeter, measuring soybean frontage, registered two miles. On a line with the car windshield two observers, starting heel to heel, walked a given number of paces in opposite directions parallel to the road, then turned into the field and walked another given number of paces at right angles, into the field. The two numbers, which were different for each observer at each stop, were between 0 and 100 and were each determined by drawing numbered tokens at random from a sack. (It would have been better for the first number in each case to have been between 10 and 110, to avoid border effect). Beginning at the position of the foot on the last pace, an L-shaped sample was taken consisting of 3 feet of row plus 1 foot of each of the first three rows to the left of, and in line with, the third foot of the 3-foot row sample.

In exceptional cases non-random sampling may be desirable. In a survey for rare and new diseases, for example, with emphasis on discovery rather than measurement of prevalence, it would be justifiable to concentrate attention on farms that are uncared for or abandoned, where no effort is made to control disease.

ROADSIDE APPRAISAL WITHOUT FIELD SAMPLING: -- When the presence and amount of a plant disease is conspicuously apparent from a distance, the possibility of surveying from a moving automobile or airplane can be considered, this having an enormous advantage in rapidity and economy. This principle has long been used in appraising crop acreages and other phases of land use. The roadside frontage can be quite accurately measured, originally by counting the evenly-spaced telegraph poles, from a railroad car, later by recording mileages as registered by the automobile speedometer, and now by equipping the car with a cropmeter, an instrument designed for measuring frontages in feet. From our point of view such a method must be considered in the light of several factors: Is the frontage proportionate to the total acreage; is the pathological situation seen from the car representative of the whole countryside; are the observations obscured or invalidated by "border effect"? However, these questions can all be answered by study.

HOUSEMAN et al. (1946) have analyzed the first of these questions. They cite studies by HENDRICKS showing that roadside frontages are proportionate to acreages in the cases of corn, alfalfa, and wheat, but that with some other crops the frontages do not correspond to the acreages because of a tendency to plant certain crops at the roadside and others (e.g., bottomland crops, crops subject to poaching) away from the road. In their own study it was found that in Illinois there was a tendency to plant soybeans away from the road, but the roadside data could be corrected for this by use of an easily-determined constant relating acreage to frontage.

In surveying for plant diseases there is the further question whether certain diseases tend to be more prevalent in fields that border roads than in those away from the roads. The latter is most likely, both because of pride on the part of growers which leads them to attempts at control of diseases in fields that are seen by passers-by, and because the better, more valuable farms, those where control practices would most probably be used, tend to have a higher percentage of frontage along well-travelled roads than do the poorer farms. This source of error, where it exists, could be eliminated by determining the correction factor for disease and frontage by means of a study of this relationship, on foot in sample areas, and then correcting the roadside readings by this factor.

Our best illustration of this method of surveying is the work of EZEKIEL and TAUBENHAUS (1934) and EZEKIEL (1938) in surveying for Texas root rot. This disease occurs in large or small irregularly distributed spots in the field, and is unevenly distributed from one field to another, and with direct sampling it would be necessary to use very large samples because of this irregularity. The spots can easily be observed from a considerable distance.

In their automobile surveys the Texas workers estimated the percent to which fields were occupied by the root rot spots and in five days were able to appraise 770 fields. When the estimates were compared with actual field counts the two methods invariably were in close agreement.

AIRPLANE SURVEYING: -- This method has been much more extensively used in surveying for insect pest infestations than with plant diseases, yet it has a useful place in surveying for those diseases that are conspicuous from the air, such as Texas root rot (Figure 18), dry land foot rot of cereals, cherry yellows, cereal leaf rusts, and dodder.

Figure 18. Aerial photograph of cotton field heavily attacked by Texas root rot, the cause of the dead plants, illustrating the usefulness of aerial survey methods. (Courtesy, A. A. DUNLAP, Texas Agricultural Experiment Station).

Aerial surveying, besides its speed and economy, has the further advantage that it may include aerial photography, in black and white or, better, in color, documenting the survey data with objective photographic records which can be very accurately analyzed by measuring the areas of infestation with a planimeter. In many respects the most striking case of plant disease that the writer has been privileged to see was a general infestation of dry land foot rot in wheat, which showed from the air at harvest time as great black spots, involving 30% of a vast acreage, where the dead wheat, overrun with sooty molds, stood out in sharp contrast to the sunlit golden color of the healthy ripened grain.

The Iowa Statistical Laboratory is using the method of strip-sampling with aerial colored photographs to aid estimation of grain production and quality; a similar practice might well be used for any plant disease that noticeably discolors the crop. The U. S. Department of Agriculture has made successful use of the autogyro in surveying for the Dutch elm disease, where the dead branches of diseased trees are more easily seen than from the ground.

Entomologists have learned the value of airplane surveys, which have been used effectively in surveying for mosquito breeding areas, the hemlock looper, the spruce sawfly and budworm, and the wattle bagworm in Africa. For surveys of forest insects in densely wooded areas with few roads, such as the Gaspé Peninsula, the airplane may be the only effective and practical means of surveying.

A particularly valuable contribution is that of F. E. WHITEHEAD and FENTON (1940) on airplane surveying for greenbug (aphid) injury to cereals in Oklahoma. This insect produces spots of dead grain with bright yellow margins, that are easily seen from the air and distinguishable from other types of spots. The surveying was done at 500-foot altitude, dipping the plane lower in questionable cases. The survey of 47 counties required 24 1/4 hrs. of flying time and cost $163.50 or 8 to 10 cents per mile, which was about half the cost of a comparable survey by car. It was completed 5 1/2 days after the outbreak was first discovered and in 2 1/2 days more all interested persons had been notified and control practices were being undertaken. The forecast of injury, based on the air survey, proved to be "surprisingly accurate" when confirmed later by questionnaires. Besides the advantages of speed and economy, the air survey proved more thorough than a ground survey could have been, because of limited visibility from the ground, the fact that the plane was not limited by roads, and that it was possible to see grain fields and infestations over a broad area, so that the plane was able to follow more efficient routes than an automobile could have done. All of these advantages have their counterparts in plant disease surveying by air.

While most air surveying has been done with conventional types of planes, the light, low-speed models being preferred, the slow autogyro has shown advantages in surveying for the Dutch elm disease, and, in the future, the helicopter, with its complete maneuverability, speed control, and safety at low altitudes, promises to be most useful of all.

No account of airplane surveying would be complete without reference to the use of aircraft, as well as kites and balloons, in sampling the air for the presence of fungus spores, insects, and other airborne particles. This type of work has developed principally in connection with air surveys of spores of cereal rusts and downy mildews, with the findings correlated with concomitant and subsequent disease development, and used in the study of long-distance dissemination of diseases. An extended account of this type of work is given in the symposium "Aerobiology", published by the American Association for the Advancement of Science in 1942.

INTENSIVE VERSUS EXTENSIVE SAMPLING: -- By intensive sampling we mean very thorough examinations of tracts or populations of limited size, in contrast to extensive sampling, over a broad area with less thoroughness. Each has its uses, and a combination of the two is sometimes the best procedure.

Such a combination has been the writer's regular practice in sampling for wheat leaf rust, as a basis for forecasting rust outbreaks. The intensive sampling is a detailed study of rust development of one or a few standard observation fields, with frequent examinations of many leaves, sometimes thousands of leaves per sampling when the rust level is low. During the last week of March in each year this intensive sampling is supplemented by an extensive, statewide sampling, with brief observations of hundreds of fields, to determine whether the results of the intensive sampling have broad territorial application.

In forest appraisal a similar practice has been recommended by LEXEN (1947) called "double sampling". The large sample, which may consist of 2000 trees or more, depending on the skill of the appraiser, permits a preliminary rough estimate of the apparent volume of timber in the forest and may show as high as 35% error. This is corrected by the intensive small sample. In making the large sampling, data are taken on tree height and diameter, with volume of wood being estimated, while in the small sampling, trees taken at random from the large sample are felled, bucked into logs, and the actual gross volume and cull volume are measured. The number of trees in the small sample depends on the amount of defect in the stand; it is greatest in old, defective virgin timber where there is the least agreement between estimated and actual net timber volume.

The advantages of double sampling justify its use rather generally in plant disease surveying. It is particularly desirable in connection with automobile roadside or airplane surveying, both of which are extensive methods, since such surveys must be controlled and validated by intensive study of selected fields.

THE TELEPHONE AS A SURVEY TOOL: -- NEIL STEVENS, to whom we owe many original suggestions on surveying practice, has stressed (1945) the desirability of making greater use of the long distance telephone as an adjunct to surveying which is cheaper than the time and gasoline used in travel. It is a method that deserves more extensive use.

THE IOWA MASTER SAMPLE PLAN: -- The Master Sample Plan is a form of area sampling. Its operation is based on use of large scale aerial photographs involving nearly every county in the United States. Sampling units, such as quarter-sections, are located at random on the maps, and these ultimate units are sampled by questionnaires addressed to dwellers on the units or by interview or personal inspection of the units, or by a combination of these. The size of the sample, _i. e._, number of units, is large or small according to the needs and purposes of any given survey.

The idea of a Master Sample first occurred to RENSIS LIKERT of the U. S. Bureau of Agricultural Economics in 1943 (KING and JESSEN, 1945). It was decided to work out the project through the Iowa State College Statistical Laboratory because of the sampling experience of the Iowa group. The size of the sample, originally planned to include 5000 farms, was increased to 300,000 farms when the Division of Agricultural Statistics became interested in the Master Sample as a basis for large scale farm surveys. The U. S. Bureau of the Census also was concerned in using the Master Sample in connection with the 1945 Agricultural Census, since it could provide a group of farms suitable for preliminary sampling. Under a cooperative agreement the Master Sample was completed in time to be used in the 1945 Agricultural Census as planned. The three agencies have cooperated in the planning and execution, as a million dollar project, of the further development of the Master Sample. Other governmental agencies and private industries have become interested and made use of the services of the Iowa Laboratory.

The area method of sampling has advantages over other sampling designs because: (a) it is independent of any predetermined knowledge of the characteristics of the population (a weakness of many public opinion polls in which the advance conception of population characteristics is nonrepresentative); (b) it is purely objective, eliminating freedom of choice on the part of the surveyor; and (c) it is usually efficient from the standpoint of maximizing precision on the basis of cost. While the initial cost of designing area sampling is high it has been found justified by the many uses of the Master Sample (KING and JESSEN, 1945; KING _et al._, 1945; Anon., 1946).

The Master Sample Plan has been put to many and varied uses. In agriculture it has served to determine acreages and crop production, farm land ownership, farm employment, numbers of livestock bought, sold, and on hand, farm receipts and expenditures. Service for industry has included surveys to determine markets for farm and household equipment, magazine readership,

and radio program preferences. Two of the most unusual uses of this technique were the collection of data for the World War II European Strategic Bombing survey and the 1946 survey of fairness in Greek election activities. It has also been useful in ascertaining farm and city populations.

On page 278 mention is made of the use of the Master Sample in determining the amounts and causes of livestock morbidity. An exact parallel exists between this problem and that of insect pest and plant disease losses. Thus far the Master Sample has not been used in plant pest surveying, yet it would undoubtedly have much value for this purpose and it is hoped that this valuable new technique will soon be applied to plant disease and insect pest surveying.

Chapter VI

ORGANIZED PLANT DISEASE SURVEYS

It is the purpose of this chapter to describe briefly the plant disease surveys that have been conducted by various State, Federal, and private agencies, in America and abroad, with mention of comparable surveys of insect pests and livestock diseases.

U. S. DEPARTMENT OF AGRICULTURE, PLANT DISEASE SURVEY: -- Prior to 1917 there were scattered attempts at plant disease surveying, one of the earliest of which was the potato late blight survey of 1885 and 1886, conducted on a questionnaire basis by the U. S. Department of Agriculture (N. E. STEVENS, 1934a).

Thanks largely to the interest and efforts of W. A. ORTON, the Plant Disease Survey was organized as an office of the Bureau of Plant Industry, U. S. Department of Agriculture, on July 1, 1917 with G. R. LYMAN, in charge, assisted by R. J. HASKELL. In later years it was directed successively by N. E. STEVENS, H. A. EDSON, and P. R. MILLER. The principal objects of the survey, as originally stated, were "first, to collect information on plant diseases in the United States covering such topics as prevalence, geographical distribution, severity, etc., and, second, to make this information immediately available to all persons interested, especially to those concerned with disease control." Soon after the initiation of the survey, LYMAN (1918) described its organization, value, and objectives, and appealed to pathologists to support and cooperate with the new undertaking.

Plant pathologists and mycologists in the various States have been selected as volunteer cooperators with the Survey. Survey data from the States are routed to the Survey office in Washington where they are coordinated and published in the mimeographed Plant Disease Reporter, which was initiated as the Plant Disease Bulletin in 1917, and received its present title in 1923. In addition to organizing and coordinating miscellaneous State survey activities throughout the country, the small staff of the Survey office has conducted a number of regional or nation-wide special surveys, such as those of the wheat smuts, leaf rust, nematode, and take-all or mosaic, corn root rot and brown spot, potato wart, and alfalfa stem nematode in the earlier years, and the cotton seedling disease and boll rot surveys and the tobacco disease surveys of more recent times.

The regular issues of the Plant Disease Reporter contain a miscellany of reports on various and sundry plant disease occurrences, distributions, losses, forecasts, etc. Supplements have been devoted to more extended treatments of special surveys, check lists, host indexes, cooperative control experiments, epiphytotics, survey techniques, and annual national summaries. The latter have been of two sorts. One contained summaries of all disease data reported during the year, arranged by crops. The other summarized estimates of loss caused by principal diseases of leading crops. Both types of annual reports were discontinued after 1939. This is unfortunate, as both, despite their limitations, were valuable sources of disease intensity and loss data. The annual disease loss reports were based on estimates of loss in the various States, made by the principal Survey collaborators, usually with the assistance of other State specialists. These loss estimates were sometimes little better than guesses, and in numerous cases were demonstrably too low (WOOD, 1935). Yet they represented the only available comprehensive body of data on losses from plant diseases in the United States, and they were undoubtedly more reliable than some other published disease loss estimates. It is hoped that they will again be issued regularly, and it seems assured that in that case their reliability and usefulness would constantly increase as the experience of passing years adds to the accuracy of our loss appraisals.

During World War II it became appreciated that the immediate recognition of crop disease outbreaks, whether fortuitous or by enemy design, was of vital importance to national security, and in 1943, with the approval of the Secretary of War and support from the President's emergency funds, the Plant Disease Survey established the emergency plant disease prevention project, with 24 survey pathologists assigned to territories throughout the United States. Disease identification laboratories to serve these field men were established at Beltsville, Maryland and Stillwater, Oklahoma, with consulting diagnosticians in charge.

These "G-Men of Plant Disease", as P. R. MILLER Has called them, gave particular attention to important food crops and sent weekly reports to the Survey. Much of the information on old and new plant diseases which was disclosed by these surveyors was published in the Plant Disease Reporter during the war years, after which this emergency activity of the Survey was discontinued. Interesting accounts of the more significant discoveries made by these men and of their use in loss-prevention programs have been given by BARSS (1944), P. R. MILLER (1947b), and P. R. MILLER and WOOD (1947).

Another significant advance in the work of the Plant Disease Survey was marked by the Research and Marketing Act of 1946 which allotted to the Survey funds for a Federal-State cooperative regional project on the establishment of facilities for forecasting the development of crop plant diseases, beginning in 1948. This was an outgrowth of the potato late blight warning service developed by MELHUS (1942) during the second world war, and of the national tomato late blight warning service organized in 1947 by the Plant Disease Survey (P. R. MILLER, 1947c; P. R. MILLER, J. I. WOOD, and others, 1947).

The work of the Forecasting Project is now limited to experimental investigation of factors involved in dissemination and severity of the diseases with which it is concerned. For this purpose, a pathologist has been stationed by the Project in each of three regions to begin with, viz. Northeast, Southeast, and North-central. The warning service, which was a part of the Forecasting Project until it was no longer on a tentative experimental basis, is now a function of the Survey proper; it is this service that gathers and relays the current information basic to the forecasts. Key pathologists coordinate disease information in each State and in cooperating Canadian Provinces, sending timely reports on the progress of the diseases to the Survey office in Washington, where they are summarized and redistributed to the key pathologists for such local action as may seem advisable.

Throughout its thirty-year history the Plant Disease Survey has been, and still is, handicapped by lack of funds and of a staff of adequate size for its important task. Considering this handicap it is remarkable how much has been accomplished, under its able and energetic leadership, in assembling plant disease data of current importance and often of lasting value, and in providing these data to the men who could make good use of them in reduction of crop disease losses through research, education, and action programs.

SPECIAL SURVEYS OF THE U. S. AGRICULTURAL EXTENSION DIVISION: -- F. C. MEIER, who became the first Federal extension plant pathologist in 1922, inherited from W. A. ORTON an interest in plant disease surveying, and conducted a number of special surveys in connection with his extension program. It was he who initiated the analysis of wheat terminal-inspection reports which has given us a long-term authoritative record of such diseases as bunt of wheat and ergot of rye.

R. J. HASKELL, who entered the Extension Service after seven years in charge of the Plant Disease Survey, continued the analysis of terminal-inspection reports until this work was taken over by the Chicago office of the Production and Marketing Administration. He also maintained his interest in disease surveys and losses, as shown, for example, by his study with E. G. BOERNER (1931) of the relation between wheat bunt in the field and smuttiness of the threshed grain.

STATE-SPONSORED PLANT DISEASE SURVEYS: -- On numerous occasions in the past, individual States, alone or in cooperation with the Plant Disease Survey or other agencies, have undertaken surveys, some for specific, limited purposes and others of a more general nature. At the present time a number of the State agricultural experiment stations include survey projects in their research programs. In the Oklahoma Station, for example, there is a continuous project entitled "Oklahoma Plant Disease Problems," designed to support work of a survey or exploratory nature, and from year to year, as natural disease outbreaks occur, these are made the subject of special surveys.

Between 1927 and 1929 general statewide surveys of plant diseases were conducted by plant pathologists of Iowa, Utah, Montana, West Virginia, and New York with cooperation and financial assistance from the Plant Disease Survey. Reports of these are found in the Plant Disease Reporter, Supplements 58, 59, 69, 72, and 76 respectively.

The most extensive of the State-sponsored plant disease surveys have been those of the Illinois Natural History Survey. Details of their methods are given in papers by TEHON (1927) and TEHON and STOUT (1930). Each year several surveyors have been in the field, taking very detailed data on the diseases of various major crops. The use of carefully planned standard data sheets has assured the completeness and uniformity of the records. For example, the data sheets used for cereal disease records have included, for each field examined, notes on: crop, disease, county, locality, crop variety, size of field, growth stage of crop, control measures (what, when, and how used), date disease first observed, source of infection, cropping and disease history of the field, association with other diseases, weather, phenology, date of observation, number attached to specimens collected, observer, and degree of infection. Where the disease in question was cereal rust, the latter has included: percent of culms infected and rust intensity in terms of the number of culms in each class of the modified COBB rust scale. With fruit diseases

the notes on infection have included: type of injury, percent of trees affected, percent infection in individual trees, percent reduction in area of leaf surface, amount of wood diseased or destroyed, and percent of twigs and of fruits infected, with the latter classified in infection scale classes. The infection data are limited to disease intensity, without the purpose of determining losses sustained. However, in cases in which disease intensity-loss relationships are known or can be determined, these data could be translated into loss estimates.

The thoroughness of the Illinois surveys, the great detail and uniformity of their records, and their long continuance make these surveys unique in plant pathology. Over the years a wealth of valuable records have been accumulated by the Illinois workers, a repository of plant disease survey data that in many respects is unequalled elsewhere. This accumulated information could be of great value in studies of the ecology of plant disease, plant disease losses, secular trends of diseases, and other aspects of plant pathology. This repository bears a relation to plant pathology corresponding to the relation between long-term weather records and the science of meteorology, or between a great herbarium and the science of systematic botany. It would be a distinct service to plant pathology if the Illinois survey records could be subjected to thorough analysis and statistical study, by qualified plant pathologists of different interests and viewpoints, as it is only through such digestion and analysis that large accumulations of survey data can be made fully useful.

While not the product of organized surveys, mention should be made of the disease and fungus check lists and host indexes of plant diseases that have been prepared for a number of States. Those for Texas, Maine, Missouri, and Oklahoma are representative of general lists of this sort, while, in other cases, the lists are more specialized, as with the lists of ascomycetes of Georgia, or of the parasitic fungi on cereals and grasses in Oregon. On a national scale, WEISS of the Plant Disease Survey published in the Plant Disease Reporter between 1940 and 1949, a revision of the "Check List of Diseases of Economic Plants in the United States", which originally appeared in 1926 as U. S. Department of Agriculture, Dept. Bull. 1366. While these check lists do not give much information on prevalence, intensity, or destructiveness of plant diseases, they are valuable sources of data on disease distribution, with many useful applications to the problem of present and potential disease hazards.

No account of State-sponsored surveys would be complete without some mention of the Iowa Master Sample which is used for many other types of surveys than those for plant disease. This has been discussed in detail previously (page 268), and here it is sufficient to recall that this is a means, developed in Iowa but used extensively in other States, for obtaining a representative sampling, of any desired degree of reliability, on a geographic basis. VESTAL'S (1944) survey of the adoption of disease-resistant oat varieties in Iowa is a phytopathological application of this principle of surveying.

CROP REPORTING SERVICE OF THE U. S. BUREAU OF AGRICULTURAL ECONOMICS: -- For more than 100 years there has been national interest in the collection of crop statistics. The report of the Commissioner of Patents for 1845 devoted nearly 1100 pages to statistics and miscellaneous information on agriculture, with much space being given to potato diseases. When the U. S. Department of Agriculture was created in 1862 its purposes were defined to include the collection of agricultural statistics, and immediately there was organized a system of volunteer crop reporters to furnish periodic data on the condition of crops and livestock. Beginning with some 2000 northern farmers as volunteer reporters in 1863, the organization has grown to include over 200,000 correspondents who report in 10,000,000 questionnaires each year.

The Crop Reporting Service has continued to function under a variety of administrations, first of which was the Division of Statistics in the last quarter of the 19th century, which became the Bureau of Statistics in 1903. The program was later under the Bureau of Crop Estimates, and since 1922 it has been conducted by the Bureau of Agricultural Economics, except for an interlude in 1939-1945 when the Crop Reporting Service was first a part of the work of the short-lived Agricultural Marketing Service and later temporarily under the Agricultural Marketing Administration.

Despite its great extent and thorough coverage, and its well-established value for determining crop production, land use, and many other agricultural matters, the Crop Reporting Service has so far produced few reliable data regarding plant diseases. In fact, the scanty disease data from this source which have been published have usually shown such gross error that they have obscured rather than aided in an understanding of plant disease losses. This would be expected, considering that the crop reporters who provide the basic data are generally unacquainted with the nature of crop diseases and, have an almost universal tendency to ascribe to unfavorable weather or soil the reductions in yield that are caused by plant disease. An example of their

underestimation is given on page 217.

If it were possible to attain reasonable reliability in plant disease reports of the Crop Reporting Service, this would be a source of survey data of scope and extensity far exceeding any plant disease survey yet attempted. It may be vain to hope that the necessary degree of reliability could ever be obtained in data submitted by untrained farmers. Yet, present-day agricultural education is doing much and can do much more in the future, in familiarizing growers with their production hazards. Some improvement in the reliability of farmers' appraisal of crop damage from disease is bound to accompany this gradual process of education. It could be accelerated by planned efforts in training the survey specialists who coordinate and verify the reports of lay collaborators, so that they, the survey specialists, can give due weight to the disease hazard in their own reports, and aid in securing more reliable disease reports from collaborators. At the end of this book a concrete proposal for such training is given.

REPORTS OF THE FEDERAL CROP INSURANCE CORPORATION: -- The potential value of information on crop losses as a basis for crop hazard insurance was discussed in Chapter I (page 205 ff.) where it was pointed out that the records of indemnification by the Federal Crop Insurance Corporation provide meagre data on annual disease losses as reflected in claims paid. These data have been published in Reports of the Manager of the Federal Crop Insurance Corporation for each year.

As a source of disease loss information these reports are of limited value because: (a) they are intended to include only unpreventable losses (despite some claims paid for losses from wheat smut and cotton "rust") and therefore do not reflect the relative importance of the various diseases of a given crop; (b) they are limited to very few crops and diseases; (c) the data are often limited to a few experimental counties, not giving a representative sample for large areas; (d) in many cases there is no published breakdown to show the distribution of disease indemnities among the several diseases of a crop; (e) diseases are sometimes listed under unrecognizable names as "blight" and "wilt" of wheat and "blight" of flax and tobacco; and, most important of all, (f) taken at face value the claims paid for disease losses are far below the level that would reflect their true importance among the other crop hazards, for reasons indicated on page 206.

The insurance report disease data also appear to lack appraisal uniformity from one State or season to another, so that they cannot be used as reliable indices of relative disease importance. For example, 22% of all claims for wheat insurance in New York State in 1942 were for smut losses, but there were no similar claims in 1940 or 1941. In 1940, 34% of the claims in Indiana and 45% of the claims in Wisconsin were for rust damage, while there were no claims for rust losses in the adjacent States, Ohio, and Minnesota, where rust was presumably comparable in amount to that in the indemnified States. In correspondence from the Manager of the Federal Crop Insurance Corporation it has been stated that the insurance adjusters are inadequately trained in plant pathology, which doubtless accounts for these discrepancies.

On the whole it appears that we cannot turn to the insurance reports for reliable information on crop disease losses, but it is hoped that through future education this defect can be corrected, an accomplishment that would be equally helpful to crop insurance agencies, to farmers whose crops are insured, and to plant pathology.

COMMERCIAL AND OTHER NON-GOVERNMENTAL SURVEYS: -- While most plant disease surveys in the United States have been sponsored by Federal or State governments, there are a few cases of privately supported surveys.

The fruit disease survey made by the Eastern New York Horticulture Society (Anon., 1899) has historic interest as one of the first of such surveys in this country. This survey, led by F. C. STEWART and F. H. BLODGETT, involved sending 250 circular letters to growers in 10 Hudson River counties, followed by inspection trips. The circular letter listed 36 diseases, and growers were asked to indicate those of greatest local importance, with percent crop loss, control measures used, and information on new or unusual diseases. It was found that the questionnaire method alone was unsatisfactory because replies were often careless, diseases were not accurately identified, and there was misleading use of common names of diseases. Good results were obtained, however, when this method was supplemented by the field inspections.

Commercial surveys are well illustrated by those of pea diseases in Wisconsin, made at the request of and supported by the canning industry, and conducted by F. R. JONES and LINFORD (1925) and WALKER and HARE (1943). The first survey involved 688 fields, the second, 4714 fields, and they were made by visiting each field two or three times and taking systematic, well-planned notes on incidence of and losses due to each of several diseases.

It would be to the advantage and profit of processors, marketers, and the industries dealing in seed, pesticides, and pest control equipment to support such surveys more commonly. They

can give a foreknowledge of the amount and condition of crops to be harvested, permitting economical processing and marketing, and they can reveal the most strategic points for the concentration and distribution of pest-control products or for the education of growers to the use of commercial materials and equipment in pest control.

TIMBER CRUISING AND FOREST APPRAISAL: -- Forest disease surveys, which are essential and routine parts of forestry, have been so well discussed in books on forest mensuration and forest pathology, such as that of BAXTER (1943), that they can be only mentioned here for the sake of completeness. The subject has also been discussed by WEIR (1918). Two types of surveys are included, limited intensive surveys in connection with forest value appraisal, and extensive surveys such as those to determine the ranges of chestnut blight, pine blister rust, or elm diseases.

PLANT DISEASE SURVEY OF THE CANADIAN DEPARTMENT OF AGRICULTURE: -- For nearly thirty years the Department of Agriculture of Canada has conducted an annual, Dominion-wide plant disease survey. This began as a result of action taken by the Canadian Branch of the American Phytopathological Society at its first annual meeting in 1919. W. P. FRAZER and W. H. RANKIN were appointed to undertake the work. This was done, with the ready permission of the Dominion Botanist, H. T. GÜSSOW, beginning in 1920. Through the years the Survey has continued as a routine part of the work of the Division of Botany, ably led during most of this period by I. L. CONNERS, with many professionally-trained collaborators. The results of these surveys have been published in mimeographed Annual Reports of the Canadian Plant Disease Survey, issued by the Department of Agriculture at Ottawa.

In general form these reports resemble the annual summaries of plant diseases in the United States, formerly issued by the U. S. Plant Disease Survey, with diseases classified according to crops affected, and sub-classed geographically, and with a preliminary summary of the most important pathological events of the year. A unique and valuable feature of each report is the summary of phenological data at three strategic points, beginning in 1936, with blooming dates for many herbaceous and woody plants. This, coupled with an annual summary of the effect of weather on plant diseases, provides extremely valuable source data for studying the ecology of plant diseases.

In addition to the general summaries of plant diseases, which are particularly complete for the cereal crops, some of the reports contain accounts of special survey activities, beginning with DEARNESS' list of anthracnoses in the first issue, and including provincial or local fungus lists, special surveys of diseases of tobacco, strawberries, flax, sugar beets, soybeans, and peas, reports from the District Potato Inspectors on potato virus diseases and on the vectors of these viruses, and, recently, reports of disease in the rust nurseries and of the determinations of physiologic races of cereal rusts.

As an adjunct to plant disease surveying in Canada, I. H. CROWELL and E. LAVALLÉE have published a "Check List of Diseases of Economic Plants in Canada."

BRITISH WORK IN PLANT DISEASE SURVEYING AND LOSS APPRAISAL: -- The British Ministry of Agriculture and Fisheries initiated a plant disease survey in 1917, publishing in a Miscellaneous Publication series annual "Reports on the Occurrence of Insect and Fungus Pests on Plants in England and Wales." At present the Ministry, through its plant pathology laboratory in Harpenden, also issues "Monthly Summaries of Fungus and Allied Diseases occurring in England and Wales". These are marked "not for Publication" and may not be obtained, on request, by American workers. This is unfortunate from the standpoint of disease intensity-loss study, because the reports contain numerous valuable contributions to the techniques of disease measurement in addition to many useful records of disease occurrence and ecology.

In 1933 the Plant Pathology Committee of the British Mycological Society held a symposium on the measurement of plant disease intensity (BEAUMONT et al., 1933). During the next few years the need for better methods of evaluating disease became increasingly apparent, and in February, 1941, the Committee called a special meeting at which it was decided to attempt to evolve simple, reliable standard methods of recording diseases quantitatively in the field. The subcommittee on plant disease measurement consisted of F. C. BAWDEN, R. W. MARSH, W. C. MOORE, and P. H. GREGORY, with W. BUDDIN acting as secretary.

The work was begun at once. In 1941 questionnaires were distributed and 1200 estimates of plant disease were received. Meanwhile, exploratory work was done on methods for appraising loose smut, take-all, and eyespot of wheat, virus diseases and late blight of potatoes, downy mildew and virus yellows of beets, and apple brown rot and scab.

By 1943 suitable appraisal methods for these diseases had been developed, tested, found practical, and recommended by the committee for general use (Anon., 1943). The British survey methods are discussed elsewhere in this book. They are particularly deserving of study because of the attention given to sizes and types of samples, with an effort toward the smallest samples that will give reasonably reliable results. In this brief account of British survey activities should also be mentioned the work of BEAUMONT at Seale-Hayne Agricultural College, in forecasting potato late blight. This is described in connection with methods of disease forecasting.

DANISH PLANT DISEASE SURVEYING: -- To little Denmark, long a leader in plant pathology, belongs the distinction of having first developed systematic plant disease surveying. Regular annual surveys were begun by ROSTRUP in 1884, with publication of data on the importance of various diseases and pests. This long and complete record, extending well over a half century, is a unique source of data relating disease outbreaks to meteorology.

Monthly surveys and reports of crop diseases and pests in Denmark were begun by KØLPIN RAVN in 1906 with local agricultural organizations and the State cooperating. Data were obtained both by reports from lay collaborators, of which there were 88 in 1919 and 137 in 1937, and by surveys and observations by the central phytopathological staff. Excellent use has been made of various publicity channels, mail, press, radio, and magazines, in promptly disseminating the results of the surveys, and in issuing control warnings, such as those for spraying to control imminent outbreaks of potato late blight. An account of the development of plant pathology in Denmark, including surveying, has been given by GRAM (1938).

GERMAN PLANT DISEASE SURVEYING: -- Plant protection was first organized in Germany in 1889, and from the beginning statistics on outbreaks of plant disease were published. Later as the volume of data became great, there were published annual summaries of diseases in Germany. In 1901 there was prepared a group of 70 tables giving percent injury from diseases and pests of various crop plants.

The German approach to the problem of crop losses was a statistical one. MORSTATT (1929) mentions a pamphlet in 1903 proposing on observation service for uniform records of disease intensity, leaving their analysis and translation into crop loss to the central office which became the Biological Division of the Imperial Gesundheitsamt. Such analysis of large bodies of data, submitted by lay collaborators, as in the U. S. Crop Reporting Service (page 272), is the statistical method in the sense of the German workers, contrasting with the determination of disease intensity and damage by more limited but more exact and thorough studies made by trained personnel, as in the U. S. Plant Disease Survey.

Until 1920, except in 1913-1919, extensive annual reports of insect pests and plant diseases in Germany were issued by the Ministry of the Interior. In that year the responsibility for assembling and publishing these reports was vested in the "Observation and Warning Service" of the Biological Institute, with the purpose of gathering numerical data on yield losses. An innovation was the inclusion of plant pest maps to supplement the text of the reports. In 1927, as a result of a decision made by the German Plant Protection Service, monthly crop pest and disease reports were first issued.

Under the Hitler dictatorship there was pressure to increase agricultural production, involving an intensification of the plant protection information service (BÖNING, 1936; KLEMM, 1937). At that time many thousands of annual reports of major disease occurrence in economic plants were being sent in by lay observers, organized by corps of "Vertrauensmänner", who forwarded the reports to the Biological Institute for analysis and official use. One of the sections of the German "Act for the Protection of Economic Agricultural Plants" of March 5, 1937 was concerned with the organization of plant protection through the Biological Institute in cooperation with local plant protection offices, to be established by the Reich farmer leader (Bauernführer) under the Ministry of Food and Agriculture, and with the plant inspection service (GOETZ, 1937).

The tasks of the statistical section of the service, as stated by KLEMM (1940) included: (a) determination of the distribution of pests and of the areas of their greater and lesser prevalence, (b) determination of the areas of important crop losses and the amounts of loss, and (c) the investigation of the relationships between pests, pest-areas, and environment, to aid in forecasting pest calamities, organizing national pest control, and planning of pest-control research. Whatever service this organization may have been to Germany's effort in World War II, it ended in the demolition of the Biological Institute during the bombing of adjacent military objectives.

RUSSIAN PLANT DISEASE SURVEYING: -- It has been difficult to secure reliable information on Russian science, and we are fortunate that KLEMM (1941) has provided a good account of plant

disease survey and appraisal practice in the U.S.S.R.

Plant pathology became formally established in Russia with the founding of YACHEVSKI'S laboratory in 1900, followed by phytopathological sections in the agricultural experiment stations. In the early years annual lists of diseases and insect pests were published. The last year before the Revolution, 1.5 million rubles was spent on plant protection. World War I and the Revolution largely wiped out the experiment stations.

Postwar insect and plant disease outbreaks led to a reorganization and expansion of the plant protection service, with headquarters in Leningrad and many local stations, but the latter were poorly staffed and equipped. By 1930 there were 600 plant protection workers in 109 stations. Booklets of instructions on methods for observing plant diseases were prepared by MURAVEV and SHEVCHENKO (1938), DEMIDOVA (1928), NEVODOVSKII (1925) and STRAKHOV (1925). YACHEVSKI in 1929 published a very detailed analysis of the need for a Russian plant disease appraisal service.

To meet the great problem of plant protection on the many collective farm units, in 1930 the plant protection service was again reorganized as the All-Russian Union for Pest Control (OBV) for action programs, with research delegated to VISRA, the All-Russian Institute for Plant Protection, an affiliate of the Lenin Academy. With this stronger organization OBV developed a far-reaching plant disease observation and warning service with the task of determining: (a) the distribution of plant pests (diseases, insects, weeds), their places of reproduction, and their long-range prognosis; (b) the process of annual development of pests and their short-range prognosis; (c) losses caused by pests; (d) the effectiveness of pest-control measures; and (e) the influences of natural and cultural factors on the reproduction of pests.

By 1934 observation data were being assembled at 267 observation points, from 37,000 correspondents. All data were forwarded to the central office where they were analyzed and 10-day, monthly, and annual reports were issued. Despite their volume, most of the data were unreliable because of the lack of training of the observers, and the organization was defective in placing too great responsibility in the action agency, OBV. Accordingly, in 1934 it was again reorganized, this time putting the responsibility for collecting the primary observation data in the hands of the collective farms and smaller administrative units with central leadership in the offices concerned with production of individual crops. The observation and warning service was assigned to the land administrations in the People's Commissariat for Agriculture (NKS) in each republic. However, the professional work of prognosis, investigation of damage, determination of losses, investigation of the relationship between environment and pest outbreaks, and evaluation of pest control measures was delegated to the Observation Section of the All-Russian Institute, VISRA. The number of observation points was reduced to 123, each with work areas 20 to 30 km. in diameter and staffed with 3 to 5 trained crop pest scientists.

At the observation points detailed studies were made of the increase of pests, their distribution, and their effects on yield as seen in comparisons of protected and unprotected plots. Reports, including local phenology and pest forecasts, were sent to VISRA headquarters where reports were prepared on the development of pests, their overwintering, first appearance, and intensity, long- and short-range prognoses for leading pests, the regional distribution of pests, the results of research and regulation in decreasing the cost of pest-control, and methods and instructions on observation for observers on the collective farms. The tasks of VISRA, inter alia have included, for all Russia, the determination of methods for appraising crop pests, investigation of the laws governing the increase of pests, and working out methods for pest forecasting. Much of its work has been conducted in a network of substations and six zonal stations.

PLANT DISEASE SURVEYING IN OTHER COUNTRIES: -- The phytopathological services in Italy originated in the Act of 26th June, 1913, for the prevention and control of plant diseases, which became law in 1916 (TRAVERSO, 1923). The machinery of the services included regional phytopathological observatories or stations, of which 23 were formed in 1917, these being partly regulatory and partly concerned with observation, collection of data on plant disease occurrences, and information services. A noteworthy item in the Italian work is its contribution to forecasting outbreaks of grape mildew (page 328).

Reports of systematic, periodic plant disease surveys in other countries have not been encountered, although it is entirely possible that organized surveys may function in certain other nations. Check lists of plant diseases in various countries, such as Sweden and Czechoslovakia, testify to an interest in plant disease surveying even though this may not be a routine practice. The literature also gives evidence of occasional special plant disease surveys abroad, as that of South New Zealand in 1935-1936. The reports of the Minister of Agriculture of Ceylon mention a "Survey Department". Finally, a few special plant disease surveys abroad have been made by foreigners with only temporary participation of the governments of the countries concerned. In

this category fall the survey of plant diseases and fungi in Egypt made by MELCHERS in 1927-1928 (1931) and R. H. PORTER'S survey of plant diseases in East China in 1923 (1926).

SURVEYS OF THE BUREAU OF ENTOMOLOGY AND PLANT QUARANTINE: -- The several types of surveys conducted by the U. S. Bureau of Entomology and Plant Quarantine have been mentioned on page 258. These are cooperative with other Federal bureaus, with agencies in the States, including the agricultural colleges with their experiment stations and extension divisions and the State boards of agriculture, and with the pesticide industry, farmers, and other lay groups.

Comparable to the Plant Disease Survey is the Insect Pest Survey which was first organized in 1921 (HYSLOP, 1927). This maintains no field offices or field personnel but is a clearing house for many thousands of reports on insect outbreaks that are submitted weekly, each year, by some 250 collaborators throughout the United States. The survey issues weekly summaries of insect conditions and impending outbreaks during the growing season, and monthly and annual statements furnished to government workers, pesticide manufacturers and other interested persons. It aids other survey activities in pest identification and maintains a file of a half-million individual notes on insect occurrence and destructiveness.

From 1943 to 1945 the Bureau, with the aid of the President's emergency funds, conducted unique Port-of-Entry Surveys designed to detect local establishment of introduced pests around harbors and airports and along the Mexican border (SWAIN et al., 1946). These were parallel to, and cooperative with, the Emergency Plant Disease Prevention project. With personnel of 92, some 63,000 inspection hours were spent along the entire length of the Atlantic, Pacific, and Gulf coasts, and the Mexican border, and special surveys were made of pests in cork imported from Morocco and of the crambid insect, *Chilo loffini*, in California. Both crop plants and their wild relatives were examined for insects and diseases; and many unusual specimens were found and submitted to specialists for identification. Apart from a number of discoveries of new or little-known but important infestations, much incidental information was gathered, which in itself went far to justify the expenditure of funds.

Most other survey activities of the Bureau, usually cooperative with State agencies, are classified as surveys in the domestic plant quarantine and control field. Information on these is given in the annual "Reports of the Chief of the Bureau of Entomology and Plant Quarantine". Many of these surveys are designed to delimit the areas of infestation, as those of the gypsy moth, browntail moth, Mormon cricket, pea scylla, sweet potato weevil, white-fringed beetle, and potato tuber worm. Surveys for the Dutch elm disease (*Ceratostomella ulmi*) for this purpose also involve spot inspections, well outside the limits of infestation, and include surveying for the beetle that transmits the disease as well as for the disease itself. In the case of blister rust (*Cronartium ribicola*) the surveys are aimed at delimiting the areas of occurrence and infestation of both alternate hosts, pine and *Ribes*.

It is not always possible to distinguish between survey and regulatory inspection work of the Bureau. In the case of phony peach and peach mosaic, for example, the inspection serves all three functions of locating diseased trees to be destroyed, delimiting the areas of infestation, and gathering of information on other stone fruit diseases.

Other surveys have had the purpose of determining whether newly introduced pests have escaped from their limited initial areas of infestation and become established. This has been the case with surveys for the potato rot nematode (*Ditylenchus destructor*) and with the Hall scale of stone fruits in California.

Another valuable function of the surveys is to determine the likelihood of future outbreaks of pests, permitting a pest warning or forecasting service. This has been a valuable feature of the annual grasshopper, chinchbug, and Mormon cricket surveys. In the case of sugar beet curly top, surveys of the hibernation of the vector of the virus, the beet leafhopper, make it possible to forecast curly top outbreaks before beet planting time, allowing farmers to avoid or control this destructive disease by well-advised crop management.

The annual cereal stem rust survey serves a number of useful purposes: barberry bushes, the alternate hosts of the rust, are located preparatory to their eradication; the annual development of rust in the South and in Mexico, with spread to the North, is observed over a wide area; and each year many identifications are made of the physiologic races of rust that are present, which is a guide to rust control by breeding, and which discloses the future hazards that may result from the occurrence of new races or changes in the proportions of races in the rust population.

In many cases the surveys serve to initiate pest control practices. A survey of the prevalent velvetbean caterpillar in 1946 led to prompt control measures; the screwworm survey, begun in 1943, has greatly aided a program for the treatment of infested livestock; and chinchbug surveys,

begun in 1944, direct attention to the areas where control practices are needed. Although control was not practical, the survey of the Sitka spruce beetle in 1946 led to salvage of much timber that would otherwise have been lost.

Special emergency surveys of vegetables, fruits, and cotton have recently been organized, with the primary objective of locating areas of greatest need of pesticides and channelling these to the needy areas. The cotton survey has enlisted the aid of farmers, 4-H members, vocational agricultural teachers and their students, and other State and Federal agencies. Weekly reports are issued to cooperators and the pesticide industry is kept informed about the areas where its products are in greatest demand.

The entomological surveys often make use of ingenious or unusual methods. Insect traps are frequently and widely used in surveying outside the known areas of infestation to locate the activity of such insects as the pear scylla, Japanese beetle, oriental fruit moth, and Mexican fruit fly. Survey inspections of cotton gin trash give valuable information on infestations of the pink bollworm. In 1945 the Bureau developed the soil-wash method of surveying for the golden nematode of potatoes (Heterodera rostochiensis), which has proven to be a useful method for locating this pest.

THE U. S. LIVESTOCK MORBIDITY AND MORTALITY SURVEY: -- In 1944 the National Research Council formed an Agricultural Board which established a Committee on Veterinary Services for Farm Animals under the able chairmanship of R. C. NEWTON, vice-president of the leading meat-packing organization, Swift and Company. The object of the committee was to increase the efficiency of livestock production by reducing losses. The committee soon found that little was known of the economics of livestock morbidity and mortality. As B. T. SIMMS, Chief of the Bureau of Animal Industry and a member of the committee, expressed it: "The simple fact is that no comprehensive information concerning animal losses -- either total losses from death or loss of profits through sickness -- is at present obtainable. If the losses were known, their enormous proportions would probably quickly bring about remedial measures."

The immediate task, then, was to assemble reliable information on the extent of livestock losses. Several interested agencies recommended to the directors of the State agricultural experiment stations that they initiate studies on the economics of morbidity and mortality in livestock. At that time the recently organized Statistical Laboratory at Iowa State College of Agriculture, in cooperation with the Bureau of Agricultural Economics and the Bureau of Census, was attracting national attention by its success in the use of the "Master Sample Plan" (see page 268), for surveying to obtain information on diverse questions. The interest of the Iowa statisticians was enlisted and a direct survey of United States farms was considered. A plan for a one-year project, limited to Iowa, was drawn up by the Statistical Laboratory and approved by the U. S. Department of Agriculture.

The problem of financing the project was solved when Swift and Company provided sufficient money for the one-year undertaking. The survey, based on the reports of livestock farmers on 177 farms in 20 scattered counties, was completed in 1947 and showed that the annual loss in Iowa from morbidity in swine was $14,000,000 and in cattle, $11,000,000. Iowa veterinarians estimated that $13,000,000 of these losses could be prevented with practical preventive measures and $18,000,000 under ideal conditions (Anon., 1948).

These estimates are subject to a high standard error (12-21% of the mean) because of the small sample size, and they have the imperfections to be expected when a survey is based on reports of untrained observers, yet they represent a notable advance in extending knowledge of livestock losses, one that should be a valuable guide in shaping a program of reduction of these losses as techniques improve and the survey expands to involve a greater area and larger period of time. The Iowa livestock survey also illustrates the use of a survey technique that deserves trial in appraising losses from plant diseases and insect pests.

Chapter VII

STATISTICAL AND HISTORICAL METHODS FOR DETERMINING DISEASE INTENSITY-LOSS RELATIONSHIPS

Having determined the intensity of plant disease it is necessary to establish the relationship that exists between disease intensity and the loss produced, the second major step in plant disease appraisal.

Many examples might be cited to illustrate the variation of correlation between disease intensity and commercial loss from different diseases. TEHON and STOUT (1930) found, for instance, that in Illinois, apple scab (Venturia inaequalis) regularly showed a higher intensity, i. e., percent of apples affected, than brown rot of stone fruits, yet the commercial loss in this case was much greater for brown rot. Tomato anthracnose (page 216) is another case in point.

We are only led into error if we conclude that because a disease is abundant a high loss necessarily results, or the reverse of this. Judgment or intuition cannot be trusted; we must learn from investigations the amounts of loss associated with given disease intensities. Such investigations fall into two major categories; statistical or historical methods may be used, as outlined in this chapter, or the experimental approach, described in the next two chapters, may be followed. As a general rule no one method is most generally useful; different methods are most suitable for appraising different diseases, and frequently a combination of several methods is preferable to any one of them.

With some types of disease, such as the virus diseases and Fusarium wilts, which are systemic, it is much easier to correlate disease intensity and loss than with diseases in which infection is local. Usually it is simpler to determine intensity-loss relationships with diseases than with animal pests, since disease intensity is expressed in terms related to plant reaction, while the intensity of insect or other animal attacks ordinarily must be expressed as pest population, i. e., the emphasis is often on the pest rather than on the host.

Less professional training is required to determine plant disease intensity than to translate this into losses. For this reason it is a common practice, as in the German and Russian plant disease survey organizations, for disease intensity data, collected by relatively untrained observers, to be forwarded to a central office for analysis and interpretation by specialists. However, in those cases in which the disease intensity-loss ratio has been worked out and found to be relatively constant, this ratio can be applied by the original observer to his disease intensity data, converting them to loss data.

USES AND LIMITATIONS OF THE STATISTICAL METHOD: -- By the "statistical method" as the term has been commonly used abroad, is meant the assembly and analysis of many individual reports of disease intensity or loss, with the assumption that errors in individual reports will be rendered non-significant by averaging a large volume of reports, which requires the further assumption that overestimates tend to balance underestimates. This is a basic principle in the collection and use of data by the Crop Reporting Service (page 272), which may be regarded as the most outstanding example of the statistical method in agriculture.

The origin of the statistical method in Germany traces back at least a century to SCHLEIDEN (1850) who recommended it to the exclusion of other plant pathological activities: "Instead of writing thick books or even little libraries on the nature and control of plant diseases, we would do better to assemble basic statistical data, to determine, by estimates, the average losses from diseases, so that we may avoid these losses by foresight" (l. c., pp. 474-475). SCHLEIDEN, who believed that plant diseases are inevitable and only result from cultivating crops in unnatural environments, considered that we must determine average losses and then avoid them, on a national scale, by planting a sufficient excess of acreage to compensate for the loss.

In 1909 the pioneer plant pathologist, SORAUER, took up the torch for the statistical method with the proposal that it be applied internationally in an effort to secure reliable data on the cereal rusts. The chief purpose was to analyze the effects of environment on rust development and destructiveness.

SORAUER'S data showed many conflicts, most of which he believed to be explainable; reports of heavy rust with no yield reduction were attributed to lateness of attack or crop varietal resistance. Despite his faith in the method, it led SORAUER to some conclusions which we now know are not valid, for example, the misconception that rust is favored by a reduction in the vitality of the host plant due to any unfavorable environmental factor.

RIEHM (1910) criticized or even ridiculed SORAUER'S statistical findings, without presenting logical reasoning for so doing, and disregarding the fact that a diseased crop of very high potential yield may still yield fairly well despite an important reduction from potential yield. In his

rebuttal (in RIEHM, 1910) SORAUER defends the usefulness of his experimentation with pathological statistics. "It is only schoolboy quarreling about what 'statistics' means. I mean the significance of large majorities, and stand firm in my previous position that statistics can become a valuable means of obtaining information for phytopathology."

The statistical approach did become established and highly developed in Germany (MORSTATT, 1929; KLEMM, 1940. See also page 275). Its limitations have become recognized and its results have been interpreted with caution. It has been limited to a few, easily recognized pests and found useful for some purposes but not all. The principal limitation is inadequate training of lay cooperators, and a need for correcting this by more adequate instruction in the schools has been stressed by BÖNING (1936).

The basic weakness of the statistical approach is the assumption that inaccuracies in pest appraisal are reduced to insignificance provided that a sufficiently large collection of data, from many observers, is averaged. The history of science is replete with instances, from GALILEO down, in which large majorities of observers have entertained the same misconception, and that of plant pathology is no exception. The validity of average opinion does not necessarily increase as the size of the sample increases; the reverse may be true, since a popular opinion, whether true or false, becomes adopted by many uncritical or unobservant individuals merely because it is popular. The U. S. Crop Reporting Service is the world's most extensive application of the statistical method in the sense of SORAUER and RIEHM, and while its findings are highly accurate as respects easily observed or measured variants, such as acreages of given crops or crop yields, we have already seen (page 217) how inaccurate these mass opinions may be when they concern less readily observed quantities, the amounts of loss caused by plant diseases in particular.

USES AND LIMITATIONS OF QUESTIONNAIRES: -- Plant disease surveying by the use of questionnaires goes back at least to 1804 when ARTHUR YOUNG, then Secretary to the Board of Agriculture in England, used a 12-query questionnaire to determine the relation of environment and cultural practices to cereal rust outbreaks. The data from 35 replies to YOUNG'S questionnaire are given by LITTLE (1883), who used the same method for the same purpose and reported the contents of 84 replies to his 30-query questionnaire.

ERIKSSON and HENNING (1896) have reviewed the history of the use of cereal rust questionnaires prior to that time and presented results of their own use of this method. The pioneering efforts in breeding wheat for rust resistance in Australia were preceded and aided by rust questionnaires sent to wheat growers throughout the province in 1890 and 1891. More recently MELCHERS and JOHNSTON (1939) in Kansas and CHESTER (1939) in Oklahoma used questionnaires in investigating the 1938 wheat leaf rust epiphytotic. CHESTER (1944) has briefly reviewed Russian uses of cereal rust questionnaires.

Also of historical interest is the circular of inquiry regarding losses from potato late blight, sent out to several thousand correspondents by the U. S. Department of Agriculture in 1885 and 1886, discussed by NEIL STEVENS (1934a). Later HARDENBERG (1922) used a long, detailed questionnaire in a survey to determine many factors in potato culture in New York, including diseases. Reference to questionnaire surveys of cotton diseases (EZEKIEL and DUNLAP, 1940), fruit diseases (Anon., 1899), and market disease losses (P. R. MILLER, 1935) serves to show the varied use that has been made of this method of gathering data on plant disease outbreaks and losses.

Disease and insect pest report cards, used commonly in annual plant disease and insect pest surveys, represent another aspect of the questionnaire method. The report card in standard use by the U. S. Plant Disease Survey for annual summary reports from collaborators is shown in Figure 19. Special report cards have also been used at one time or another for limited groups of plant diseases, such as the cereal rusts or market diseases. The report forms used by the British Mycological Society in its plant disease surveys are much simpler (W. C. MOORE, 1943), with spaces for data on location, date, disease, variety, crop, size of field, stage of development of plants, control measures, infection data, and remarks. Analogous report forms are used in the annual Insect Pest Survey. Questionnaires or report cards are the basic tool for surveying by the "statistical method" described in the preceding section.

The principal advantage of the questionnaire or report card is its economy, permitting the gathering of hundreds or thousands of reports from voluntary cooperators at little cost. Against this advantage are two principal limitations or weaknesses. First of these is the lack of training on the part of many correspondents, which may invalidate the data. Correspondents may identify diseases incorrectly, use misleading common names of diseases, overlook important features, or fail to appreciate the significance of pathological situations. In the second place, the returns from questionnaires are rarely random samples. The many individuals who fail to return questionnaire

Crop ________ Disease ________ OKLAHOMA

Cause ________ Year ________

Crop importance (Check)	Major ____ Minor ____ Occasional plantings ____ Not grown commercially ____	Prevalence compared with last year (Check)	Much more ____ More ____ Same ____ Less ____ Much less ____	Prevalence compared with average year (Check)	Much more ____ More ____ Same ____ Less ____ Much less ____	Importance of this disease in an average year (Check)	Very ____ Moderate ____ Slight ____

Loss for State (Use figures above 0.1%; mark trace below 0.1%)	% reduction in yield ____ % loss in grade, storage, transit, etc ____ Total loss ____ Maximum % infection in any one field ____	Geographic distribution in State this year General( ) Local( ) Scattered( ) (Check) Explain ____	Earliest recorded appearance of disease this year Date ____ (Month) (Day) Place ____ (Town) (County)	Period of maximum injury Season (Check) Early ____ Mid ____ Late ____ Stage of host ____

Weather relations this year	Moisture (Check)	Favorable ____ Unfavorable ____ to disease.	Explain ____
	Temperature (Check)	Favorable ____ Unfavorable ____ to disease.	Explain ____

Varietal susceptibility this year
- Varieties immune ____
- Varieties very resistant ____
- Varieties resistant ____
- Varieties susceptible ____
- Varieties very susceptible ____

General remarks (basis of loss estimate, new work, control measures, unusual observations, etc.):

NOTE.—Do not attempt to answer all these questions unless definite data are available.

Reported by ________

GOVERNMENT PRINTING OFFICE 8—4547

Figure 19. Report card used by the U. S. Plant Disease Survey. The reverse side of the card bears an outline county map of the State in question, for indicating locations of observations.

properly filled out are likely to be the less interested, less intelligent, less energetic, and less cooperative individuals; if these are farmers the same characteritics are likely to result in a high incidence of disease on their farms, because of neglect of disease-control measures. In this case the questionnaires returned would give a falsely low picture of average disease conditions.

The first of these limitations can be reduced, if not eliminated, by exclusive use of properly trained correspondents, or by educating untrained observers in survey methods and the use of simple, fully-explained or illustrated report forms. Wherever possible, disease should be recorded in quantitative terms, and this is aided by devices such as the cereal rust scale. The education of agriculturists in accurate disease and insect pest appraisal should form a part of the training in agricultural schools. Nonscientists who act as observers can also be advantageously taught the methods of crop inspection in special classes and short courses, aided in this by simple, well-illustrated publications, lantern slides, disease specimens, and supervised field observation. For such observers the questionnaire or report form should be limited to a small number of leading and easily recognized diseases.

There are also ways of overcoming the second limitation, the error due to failures in returning questionnaires. When dealing with lay observers the questionnaires or report forms should be simple, involving only a few, clearcut questions. The cooperators can be encouraged to return the forms by educating them as to the importance and practical value of surveys. Most effective of all is to follow the questionnaire by visits to those localities or individuals from which reports have not been received, a trained surveyor furnishing the missing data. This practice is basic in surveys using the Master Sample Plan (page 268). In other cases the questionnaire data are supplemented, verified, or corrected by a limited amount of field sampling, done by survey specialists.

The shortcomings of the use of questionnaires in general are those of the "statistical method", described above. Alone, the method gives some reliable information and some that is not valid. It is dangerous to depend too heavily on this survey technique alone; it needs to be controlled by some measure of direct observation by trained personnel. Yet, because of its economy and broad scope the questionnaire method is useful and desirable when the data are conservatively interpreted and when the method is supplemented by other more direct appraisal practices.

DATA FROM MARKETING CONTROL RECORDS: -- After agricultural produce leaves the farm it becomes subject to several types of governmental or commercial inspection, the records from which frequently contribute valuable information on the prevalence of plant diseases and the losses caused by them.

Grains for interstate or foreign shipment are inspected at terminal markets by the U. S. Department of Agriculture, with its Extension Division and Production and Marketing Administration cooperating. The results are published in annual mimeographed, unnumbered summaries issued by the Chicago office. Grain is graded according to the U. S. Handbook of Official Grain Standards which recognizes the following disease categories: light smutty wheat, smutty wheat, ergoty wheat, rye, and barley, damaged kernels in corn, and blighted barley, the latter two being caused by any of several organisms.

The grain inspector's reports must be interpreted in the light of the following facts. They include only grain intended for interstate or international shipping; much grain that is transported by truck and grain that is sold to local consumers or used on the farm is not included. It is common practice for growers or grain elevator operators to hold back for local use, or sell to truckers, grain that will not pass the federal grain inspection; the inspector does not see the worst of the crop. In the Oklahoma wheat bunt epiphytotic of 1948 it was estimated that nearly half of the smutty wheat did not pass through the inspector's hands. Furthermore, diseased grain is often cleaned to remove the diseased kernels and fungus sclerotia before it is inspected. The amount of disease shown by the inspection may only be a small fraction of that which was present in the field as has been clearly shown for wheat bunt by HASKELL and BOERNER (1931). Finally, the inspection records do not include the total losses in fields that are so heavily diseased that no crop is harvested or in which the harvested crop is discarded.

For all these reasons, the grain inspection records reveal losses that fall far short of the actual losses sustained. Yet, since they are objective, reliable, and uniform from year to year they have great value, for the few diseases recorded, as indexes of the variation in the annual amount of disease and loss. It is highly indicative of the annual variations in ergot (Claviceps purpurea) of rye, for example, to note that the percent of all carloads of rye in the U. S. which graded "ergoty" was 16.7 in 1942 and 19.1 in 1943, dropping to 9.5 in 1944 and down to only 1.5 in 1945 and 1946. The value of the federal grain inspector's record as an index of annual variations in disease is borne out by its agreement with the disease trends according to U. S. Plant Disease Survey estimates, as brought out previously (page 210 and Figs. 1 and 2).

There are several types of records of post-harvest losses in perishable produce. One of these is the record of claims paid by railroads for fruit and vegetable spoilage (SHEAR, 1918) which is obtainable from the American Railway Association (NEIL STEVENS, 1933). Another source is the data on market losses determined by the U. S. Food Inspection Service. A third is the records of condemnation of produce by the boards of health of leading cities (SHEAR, 1918). RAMSEY et.al. (1947) have called attention to the Chicago law of 1927 which prohibits the dumping of produce without good reason and they have tabulated the produce for which dumping certificates were issued during a number of years.

None of these records is complete. All undervalue the transit or market losses. Claims are not paid by railroads for all losses or partial losses, nor do all cases of spoilage come to the attention of market inspectors or city officials, particularly the great volume of loss that occurs in the home. At times when the demand for produce is great, damaged produce may still be sold, although it represents quantitative and qualitative loss to the consumer.

Cannery records of yields and of damage or rejection of produce have value in indicating relative losses (e.g., H. D. BROWN, 1929; McNEW, 1943j) though they are usually incomplete. The cannery is a good base of operation for loss appraisal, since the surveyor can conveniently determine losses shown by lowered grade of the pack, and by the cull heaps of rejected produce at the cannery, while it is a central point from which the fields producing the crops for canning may be visited to determine the cull produce left at the field or loading point. Entomologists use a gin-trash machine for detecting small amounts of pink bollworm infestation in cotton, and analogous devices might be used in obtaining data on plant diseases. Few studies of this type have been made, but they can be very helpful in loss appraisal and are to be recommended for the future.

In a similar way the warehouse inspection of tobacco furnishes a good record of crop quality in this crop where lowered quality represents an important form of loss. Since the tobacco buyer is the effective judge of quality, the grading, by buyers, of experimental tobacco harvests in loss studies gives the investigator of loss a reliable and impartial measure of quality (McMURTREY, 1929).

Finally, the production, grading, and cull records of nurseries provide information on losses from such diseases as crown gall (FRACKER, 1918) and root knot. None of these sources of information in itself gives a complete picture of loss, but all are helpful in supplementing or confirming loss data from other sources.

COMPARISON OF YIELDS IN YEARS OF DIFFERENT DISEASE INTENSITY: -- Other factors

being equal, the difference between yields in a disease year and in a disease-free year would be a good measure of loss, but, unfortunately, other factors are never equal. Yet we cannot discount this as a source contributing to the total picture of loss, though not decisive in itself.

We can distinguish two types of cases: (a) those in which weather is the primary factor governing the intensity of disease, and (b) those in which the presence or absence of disease is determined primarily by controllable practices, such as spraying, seed treatment, or the use of disease-resistant varieties. It is with the former case that we are chiefly concerned at this point; the latter case is dealt with in later sections on the "historical method" (page 284) and on experimental methods in which disease in a constant environment is permitted or controlled by cultural practices.

Even when acreages, soils, crop varieties, and tillage methods remain relatively constant, crop yields vary greatly from one year to another, this variation being largely due to the interrelated effects of weather and pests. It is difficult to unravel the weather-pest complex and attribute to each factor its proper share in determining yields, yet as our knowledge advances helpful guide lines develop. We know, for example, that the occurrence of certain diseases (cereal rusts, potato late blight) is correlated with weather that is favorable for growth of the crops in question. In such cases a lowered yield during a year of severe disease is a minimal expression of loss due to the disease. In an opposite class fall those diseases which are favored by weather that is unsuitable for the best growth of the crop (many root rots). Here a lowered yield during a year of serious disease must be attributed in small or large part to the direct effect of the weather on the crop; to ascribe it to disease alone would exaggerate the loss due to disease itself.

When disease is catastrophic, obviously wiping out a large fraction of the crop, (e.g., watermelon anthracnose, peach brown rot, cereal stem rust, during certain years) it so overweighs other yield factors that the loss in yield, compared with a disease-free season, can be reliably attributed to the disease. With less spectacular diseases the problem is more difficult.

Finally, the error in this method, that is greatest when one compares only two contrasting seasons, progressively diminishes as the study is extended to include a longer series of seasons, in which the direct effects of weather on crop growth may become cancelled out statistically, increasing the reliability of disease-yield relationships.

This method as applied to cereal rusts has been discussed by NAUMOV (1939) and CHESTER (1944). Historically it was one of the first methods used in estimating rust losses (ERIKSSON and HENNING, 1896) and it is still the basis of the German practice of loss appraisal, relating yield fluctuations to pest fluctuations over a minimum of 10 years (KLEMM, 1940). The method has been used with cereal rusts in America by J. H. MILLER (1935) and WALDRON (1936) and in Russia by BRIZGALOVA (1935).

As examples of this method applied to other types of diseases, we have the loss from powdery mildew of cantaloupe in California determined by comparing yields in years of light and heavy infestation by P. A. MILLER and BARRETT (1931), a similar study of the loss in sugar beets caused by damping-off, reported by MORRIS and AFANASIEV (1945), and a very detailed investigation by CROWTHER (1941) in which the correlations between the effects of weather, soil, and disease (black arm and leaf curl) on cotton yields were determined by comparing these factors during 13 years of observations.

COMPARISON OF ANTICIPATED WITH ACTUAL YIELDS: -- Yields of crops, when the harvest is in, are often but shadows of the bountiful crops anticipated by growers and crop scouts one or several months before harvest. Hail, drought, hot winds, floods, freezes, insect enemies, and diseases -- any or several of these may have had their part in disappointing expectations.

As illustrated in the following example, a comparison of expected with actual yields, making due allowance for the various factors that have depressed the yields, is a means, although a very subjective one, of estimating the relationship between disease and crop loss. In 1921, a year of severe wheat leaf rust in Indiana, GREGORY (in MAINS, 1923) compared the wheat harvest anticipated in May with the actual yield in August, and dividing the difference among the several factors producing reduction in yield, placed the State loss due to leaf rust in the neighborhood of 10%, which agreed with independent estimates of the Soils and Crops Department and the Botany Department.

Since time immemorial this has been the method of farmers in accounting for crop losses. Without an adequate background of understanding of the nature and relative importance of loss factors it may be inaccurate and misleading in the highest degree; the most recent, unusual, or most obvious deleterious factor is usually accused of all or nearly all of the destruction, and less obvious or less well-known factors may not enter into the account at all.

In 1938, in Oklahoma, severe wheat leaf rust was forecast by the writer on April 7, and this developed as predicted. That year preharvest yield expectations ran as high as 77 million bushels.

The actual yield was 59 million. In 1948, the April 1 forecast was for very little rust, and it proved to be the year of lightest rust on record. The official May 1 yield expectation was for 75 million bushels but actually 98 million were harvested. In both years the great discrepancy between estimated and actual yield was "explained" in terms of a wide variety of factors with practically no consideration of rust, which we now know from controlled experiments caused 30% loss in the Oklahoma crop in 1938 and causes 5 to 10% loss in an average year.

In interpreting such data as these it would be unsound reasoning to disregard all of the other seasonal influences on yield, and conclude that the decrease from preharvest estimates in 1938 and the increase in 1948 were attributable exclusively or largely to rust. But is it equally unsound, knowing the effect of rust on yield, to disregard or minimize the role of rust during these years. It would seem that we have, in such figures as these, a clear indication of the magnitude of rust losses. It is not conclusive proof and it does not give us a reliable numerical expression of rust damage, but it is circumstantial evidence that is valuable in confirming loss estimates derived by other, more objective methods.

COMPARISON OF WEATHER RECORDS AND CROP PRICES IN PAST YEARS: -- BARCLAY (1892) in India attempted to determine rust damage in early years by comparing the price of wheat in given years with the record of meteorological conditions known to be conducive to rust. While there were some inconsistencies, there was evidence of a correlation between high prices, poor yields, and weather favoring rust (high humidity in January-March).

The limitations in this method are obvious: prices are regulated by many factors other than crop yields and by many yield factors other than rust; furthermore, our knowledge of the environmental conditions necessarily associated with rust is far from adequate to lead us to the conclusion that a certain year must have been a "rust year" because of its weather. Despite these shortcomings, such a procedure as BARCLAY'S is not entirely without value, as it does provide an inkling, even though it is a very conditional one, of epiphytotics of years long past.

DETERMINATION OF DISEASE IN PAST YEARS FROM EXHIBITION SAMPLES, ETC.: -- Exhibition samples, straw and other plant materials used for packing, and other types of crop residues frequently give useful clues to the occurrence of disease in past years. RUSAKOV (1929d) was able to determine the severity of rust and its presumptive destructiveness in earlier years, for which no field records were available, by examination of sheaves that had been preserved for exhibition purposes. The writer also found an interesting clue to the destructiveness of crown rust (*Puccinia coronata*) of oats many years past in the abundance of telial pustules present on the straw of a beehive that had been constructed from local materials to illustrate straw hives used in Europe. The student of plant disease appraisal will be rewarded by giving attention to such unusual sources of information.

THE HISTORICAL METHOD: -- By this term we refer to a comparison of yields before and after some fundamental change has occurred in the culture or environment of a crop, markedly affecting its pathology, e.g., the widespread adoption of an effective control measure, or the general and destructive invasion of a crop by a formerly unknown or unimportant disease.

Possibly the best documented case of the historical method is that of decline and recovery of the cane sugar industry in Louisiana, illustrated in Figure 20. Here we see the fall in sugar yield per acre from more than 20 tons to little over 10, as red rot, root rot, and mosaic successively attacked the crop, followed by recovery with introduction of disease-resistant cane varieties, a temporary setback when certain of these became disease-susceptible, and recovery again when more highly resistant varieties were introduced. During the decline, sugar production in Louisiana dropped from 400,000 tons to about 50,000 tons per year. RANDS and DOPP (1938), making liberal allowance for other loss factors, have made it clear that it was primarily this sequence of diseases that resulted in a total loss to the Louisiana sugar industry estimated at $150,000,000. Sugar cane in Brazil passed through a similar cycle (ARRUDA, 1941); between 1923 and 1925 the mosaic disease was associated with a 58% yield decline, and the introduction of mosaic-resistant cane varieties raised production from 477,000 tons in 1925 to 1,965,000 tons in 1932.

The decline of the cane sugar industry has been described by SUMMERS et.al. (1948) in the following words: "In Louisiana toward the end of that period (1916-26) yields of sugarcane had dropped to such pitifully low levels that the banks refused to risk further financing of what they regarded as a permanently collapsed industry. In Brazil a large prize was announced by a State government for the individual who could devise a 'cure' for sugar-cane mosaic, and the temper of the people most concerned in the drama everywhere could be likened to those whose means of subsistence had been snuffed out in a stock market crash with, unfortunately, the same quota of suicides."

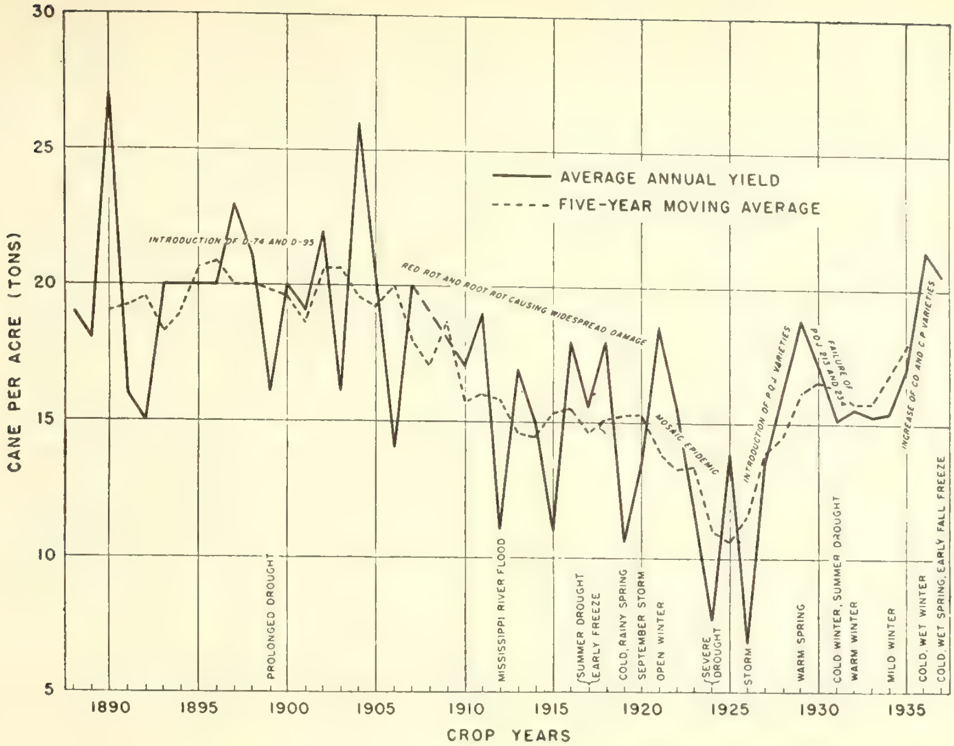


Figure 20. Decline and recovery of sugar cane yields with associated causes. (After RANDS and DOPP, 1938.)

The beet sugar industry in the Pacific Northwest passed through a comparable cycle, owing to the ravages of the curly top disease and its control by disease-resistant beet varieties (CARSNER, 1944). In 1934, 88% of the beet acreage in the Twin Falls, Idaho, area was abandoned, and the harvested acreage yielded only 4.88 tons per acre, whereas in the preceding year, when curly top was not severe, the average yield was 13.78 tons. With the introduction of resistant beet varieties yields rose to former high levels, abandoned factories were reopened, and an industry that had practically failed was reborn. In this case the disease was so pronounced in its effect that other yield factors played negligible parts in the cycle.

Hops culture in Germany passed through a similar cycle (RAGL, 1944). In 1926 downy mildew caused a loss of 30 million marks in Bavaria, the hops yield having dropped from a 1918-26 average of 720 kg. per hectare to 320 kg. At this time 6000 spray rigs were put into operation, raising average production during 1927-35 to 1440 kg.

Important acreage decreases associated with disease outbreaks have occurred in a number of other crops. During 15 years there was a 50% drop in alfalfa production in Kansas, with bacterial wilt the chief factor involved (SALMON, 1930). A 90,000 ton decrease in Utah alfalfa production was conclusively shown to be principally due to the same disease (Anon., 1938). When the California strawberry crop became attacked by yellows (virus) and the growers were forced to turn to poorer but resistant varieties, the yield dropped, during 10 years, from 120,000 to 80,000 chests per year (NEIL STEVENS, 1934b). A half century ago, when the yellows virus became a limiting factor in peach orchards, the number of peach trees in a Michigan county dropped from 654,000 to 43,000 and in a Virginia county from 130,000 to 30,000 trees (M. T. COOK, 1947).

NAUMOV (1939), who developed the concept of the historical approach in studying crop losses from diseases, selected an unfortunate example, the decline in losses from wheat stem rust in North America in the years prior to 1935, which he associated with barberry eradication. The rust epiphytotics of 1935, 1937, and 1938 do not support this explanation, but CRAIGIE'S (1944) data on Canadian wheat yields before and after the introduction of rust-resistant wheat varieties are more convincing. Here rust control has been associated with an annual yield increase of 41,339,000 bushels, valued at $27,242,000. Other spectacular yield changes associated with disease or its control include the reduction to about half of the previous barley yield in Nebraska, primarily due to root rots (LIVINGSTON, 1947), a drop in the Javan potato production from 63,000

tons in 1935 to 40,000 tons in 1940 which "can only be explained as being due to losses caused by Phytophthora attack" (THUNG, 1947), and a decrease, due to bacterial wilt (Pseudomonas solanacearum), in the tobacco crop of the South Atlantic States which between 1935 and 1945 amounted to a 10,000,000 lb. loss annually, and nearly wiped out the flue-cured tobacco industry of this region before it was restored by the wilt-resistant Oxford varieties. (T. E. SMITH, CLAYTON, and MOSS, 1945).

In another connection (page 339) further instances are given of the abandonment of crop culture due to devastating disease attacks. When these are on a sufficiently broad and permanent scale they represent other illustrations of the historical method. A case of the reverse sort is that of cereal culture in the Central Blacklands of Texas. Here, in the past, it has been considered impractical to attempt culture of wheat, oats, or barley. Doubtless this conviction traced back to early, unsuccessful attempts to grow these crops, due to leaf rusts and other diseases. In any event, the introduction of the disease-resistant Austin wheat, Ranger, Rustler, and Verde oats, and Tunis barley are extending small grain production into vast new regions of fertile soils and abundant rainfall.

From these illustrations it is clear that the student of plant disease losses can profit by making use of the historical method. It is too broad to give an accurate measure of acre losses under specified conditions, but it does furnish convincing testimony of the order of magnitude of some plant diseases. It shows that they can be destructive enough to wipe out industries and alter crop geography, and that their control can revive stricken agricultural enterprises and give birth to new ones. In addition, the historical method strikingly extends loss appraisal to involve great agricultural areas, confirming small-scale, precise loss measurement data by depicting them on a broad scale against a dramatic background of human failures and successes.

VOLUME OF PUBLICATION AS A MEASURE OF DISEASE IMPORTANCE: -- In 1939, NEIL STEVENS made the novel proposal that we can secure a comparative picture of the economic importance of diseases of various crops by use of the "disease index", which is calculated by dividing the number of pages of technical publications devoted to diseases of each crop by the value of the crop in millions of dollars. The disease indexes are given for the following crops: fruits, 30+; potatoes, 20+; flax, 14.2; rice, 4.9; barley, 3.5; wheat, 3.4; sorghum, 2.3; oats, 1.8; rye, 1.5; corn, 0.8; buckwheat, 0.0. By the same process it would be possible to determine the disease indexes of individual diseases of any given crop, using a standard, extensive bibliography, such as the Agricultural Index, as the source of data.

Unfortunately this method, however reliable it may have been for STEVENS' purposes, can be very misleading when dealing with individual plant diseases; it is not so much an index of the true relative importance of diseases as it is an index of the relative importance of diseases in the opinions of pathologists and administrators, -- a very different thing. A spectacular disease or one that is easy to work with or one that has scientific attractiveness tends to be overemphasized in the volume of publication, while other truly important diseases are neglected in the literature. A particularly active group of research workers, concentrating on diseases that are important locally but not generally, will contribute a disproportionate volume of printed matter.

Many examples of such misemphasis come to mind. There is the huge volume of literature on crown gall (Agrobacterium tumefaciens), stemming from the challenging nature of this disease and its possible relation to human cancer, which is entirely out of proportion to the economic importance of the disease. Because of the intensive work of Texas and Arizona scientists, cotton root rot, which is only locally important considering the cotton belt as a whole, is represented by a greater volume of publication than the more universal and destructive bacterial blight and Fusarium wilt diseases of cotton. Brown rot of stone fruits is probably much more destructive than the stone fruit virus diseases, yet it is poorly represented in the literature in comparison with these. The same may be said for soft rot (Erwinia carotovora) as compared with other diseases of vegetables. The volume of publication on bunt of wheat and that on the wheat root rots are in reverse order to the economic importance of these diseases. Finally, the great scientific importance of tobacco mosaic has resulted in a volume of publication that is quite out of line with the rank of this disease as an economic factor.

Although the volume of publication sometimes is a poor index of what diseases are doing, it is a very good index of what scientists are doing. This is brought out in a second paper by NEIL STEVENS (1940b) in which he uses a survey of papers abstracted in the Review of Applied Mycology between 1922 and 1938 to shed light on the amount and nature of work being done on disease control.

The writer made a similar study of the space in Phytopathology devoted to the several aspects of plant disease research, the results of which are shown in Figure 21. This is based on a paragraph-by-paragraph tabulation of the new data in the 1914, 1924, 1934, and 1944 volumes,

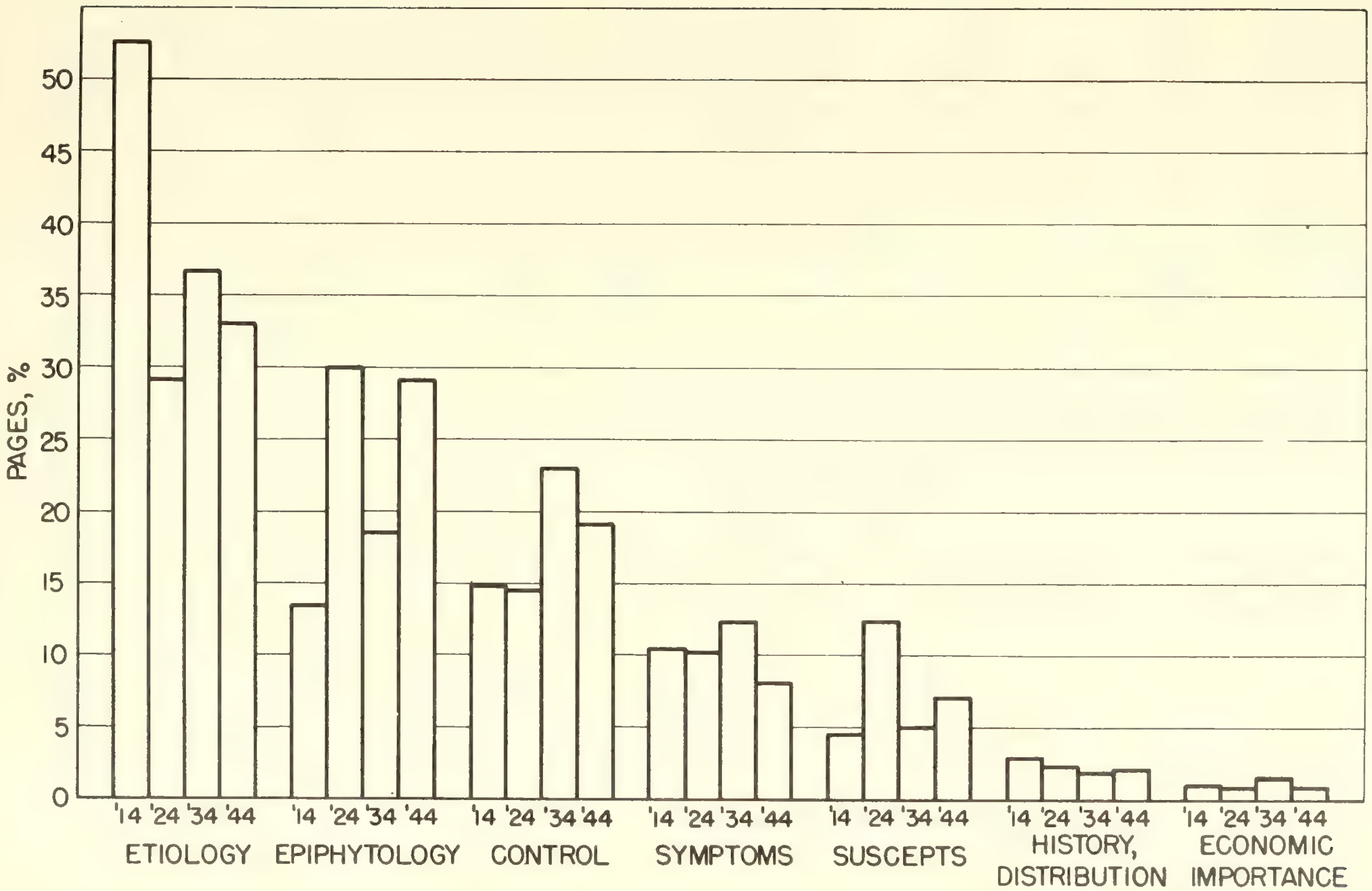


Figure 21. Percentage of pages of new data in "Phytopathology" devoted to indicated subjects in 1914, 1924, 1934, and 1944.

omitting introductory material, summaries, biographies, announcements, book reviews, abstracts, photographs, and necrologies.

There are a number of interesting conclusions that might be drawn from these data, chief of which, from the present point of view, is the almost insignificant emphasis on the economic importance of plant diseases, compared with the great emphasis on etiology. Actually only 21.6% of the papers had anything at all to say about economic importance, and in these papers the space devoted to this subject averaged only 1/3 page. The average amount of space devoted to economic importance, considering all papers, was 3 lines. In many cases, in otherwise significant papers, the economic importance of the disease worked with was dismissed with a single adjective.

The space devoted to economic importance was further subdivided into (a) general statements and (b) measurements of disease loss. Very nearly all of the space fell into the first class, but there was a healthy indication of shift from generalizations to accurate measurements of loss in 1944 as compared with earlier years.

The fair degree of uniformity of the four bars above each rubric in the figure indicates that the sample was an adequate one for its purpose. It is assumed that the journal, Phytopathology, itself is a fair sample of American plant disease publication, since it is the official organ of the science in this country.

If the sample is valid, the data reveal a deplorable indifference to the economic importance of plant diseases, the main justification for the existence of their science, on the part of plant disease scientists, an indifference which, it is hoped, may in time be overcome.

NON-PROFESSIONAL PUBLICATIONS AS SOURCES OF LOSS DATA: -- While many scientists may be loath to accept as scientific evidence data from newspapers, popular magazines, or other lay publications, there are times when such data, if not conclusive in themselves, support and confirm data from more orthodox sources. NEIL STEVENS (1945) has emphasized that while they must be handled with caution, poor records are better than none.

An excellent example of this is found in another of his papers (1944). From a study of the pH of water of cranberry bogs in the Berlin, Wisconsin, area, STEVENS came to the conclusion that a decline of this culture was associated with increasing alkalinity of flooding waters. While this conclusion was reached by direct experimental evidence of several sorts, it was confirmed by a search through files of the local newspaper and study of all articles relating to cranberry culture in early years. The first canal bringing alkaline water to the bogs was dug in 1873, and the newspaper articles gave clear indications of the good crops preceding, but not following, the use of the new source of water. They reported the large number of pickers employed in 1872 in the particular bogs in question, and the number of barrels of cranberries picked, and even confirmed this by reporting the numbers of pickers voting in a straw vote in the presidential campaign of Grant and Greeley.

McCALLAN'S INDEX OF DISEASE IMPORTANCE: -- McCALLAN (1946) expressed the importance of each of 36 leading diseases by an index which is the product of the logarithm of the farm value of the crop multiplied by the logarithm of the estimated percentage of crop loss due to disease, taken from the annual loss estimates in the Plant Disease Reporter. When McCALLAN compared the present status of use of fungicides, by crop and disease, with these indices of disease importance, with consideration of the possibility of fungicidal control of the disease in each case, he was able to designate certain outstanding diseases for which better fungicides are needed.

The use of logarithms is helpful in this procedure, since it avoids the obvious error of considering that losses of equal dollar amount are equally important, regardless of the national value of the crop. It would be unreasonable, he points out, to consider .5% loss in a $1,500,000,000 wheat crop as equal in importance to the total loss of a $7,000,000 cranberry crop or 50% loss of a $15,000,000 cantaloupe crop.

McCALLAN'S index is tentative and has its limitations, as he recognized. It is based on the loss estimates of the Plant Disease Reporter which have sometimes been widely in error. These estimates are considered to be of losses after existing control measures have been used, but in many cases a high estimated loss may be due more to failure to have applied known effective control measures, in which case education, rather than the development of new fungicides, is indicated. Nevertheless, McCALLAN'S index is a very reasonable approach to the problem of determining the relative importance of plant diseases.

DISEASE-CONTROL EXPENDITURES AS A MEASURE OF DISEASE IMPORTANCE: -- It would appear that the amount of money spent in controlling a plant disease is an index of importance, making the usually valid assumption that the losses, were the disease uncontrolled, would exceed the cost of control. The validity of this assumption has been questioned by WHETZEL and

others in connection with the expenditures for barberry eradication to control cereal stem rust and with those for various plant quarantines.

In some cases these amounts are very substantial. Between 1916 and 1944 the Federal government spent $40,000,000 for investigating, scouting, and control of pine blister rust. Eradication of citrus canker (Pseudomonas citri) cost the government $13,000,000 between 1915 and 1944, to which must be added the value of 19,000,000 citrus trees that had to be destroyed. The government has spent $21,000,000 on the Dutch elm disease (McCUBBIN, 1946). Expenditure for forest insect and disease control for the decade 1936-45 amounted to $58,000,000 (WYCKOFF, HARTLEY, and ORR, 1947). In addition there have been substantial control costs to the State governments, as Pennsylvania's $25,000 per year for the past 25 years in quarantine and eradication of the potato wart disease (Synchytrium endobioticum).

To these costs must be added the direct expense of control to growers. While it is difficult to determine this for individual diseases, the total amounts of disease-control chemicals annually sold in the United States give us an over-all index of the magnitude of disease-control expense, which we can assume is less than the cost of diseases when not controlled, since growers are careful to keep their expense of production below production income. As examples of the cost of fungicides alone, exclusive of the equipment and labor for applying them, we find that there are annually sold in the United States for disease prevention 150,000,000 lbs. of sulfur, 100,000,000 lbs. of copper sulfate, and, for preventing wood decay, 200,000,000 gal. of creosote and 5,000,000 lbs. of the zinc chlorides.

An even more serious fault in attempting to determine loss from control expenditures is the great inequality between the amounts spent on different diseases of similar importance. By far the greatest expenditures are on diseases that are controlled by government-supported quarantine and eradication programs, and for some of these the loss is not so much present as potential. Next in order of expenditures come those diseases which are controlled by chemical means. Control-cost figures give no index of the importance of diseases that may be very destructive but because of their nature or their lack of appeal to public interests have not yet been the subject of major expenditures.

In thinking of this aspect of loss appraisal one has the impression that the cart is before the horse. We are entertaining the assumption that because much money is being spent on a disease, that disease necessarily is quite important, while logic indicates that it should be the other way around, that expenditure for disease control should follow and conform to prior determination of the hazard.

Disease control expenditures do not give us comparative information on the destructiveness of different diseases. Of two diseases of equal importance one may be combatted in a program involving many millions of dollars while the other, for various reasons, is not the subject of any substantial financial outlay. But disease control expenditures are an absolute, if not a relative, measure of disease importance, for, in general, we can conclude that a disease is a major economic factor when large amounts of money continue to be spent in fighting it, although the converse of this is not true.

THE NEED FOR LITERATURE SEARCHES; THE INDEXING PROBLEM: -- In preparation for writing this book a search was made through all volumes of such periodicals as Phytopathology and the Review of Applied Mycology in an attempt to locate papers and data bearing on the several aspects of plant disease appraisal. The key words used in going through the indexes of these journals were: appraisal, crop losses, crop yields, damage, disease, estimation, insurance, intensity, losses, measurement, methods, plant diseases....., reduction, techniques, and yields. Few useful references were found by this method, and it soon became apparent that the general lack of attention to the economic aspects of plant disease is also expressed in a failure adequately to index this phase of plant pathology.

As a result it has been necessary, in this study, to depend on locating pertinent references by memory, chance, and systematically leafing through many irrelevant articles to secure the references needed. For this reason no pretense to complete coverage of the literature on disease appraisal can be made.

Considering the importance of the whole subject of disease appraisal it would be most helpful to future work if those charged with the indexing of plant disease journals would give attention to indexing the economic aspects with the same thoroughness with which the etiological aspects are indexed.

As can be seen from the bibliography at the end of this work, many references that are relevant to disease appraisal are found in journals that are not primarily devoted to plant pathology, including the literature of agronomy, horticulture, agricultural economics, entomology, and crop insurance. This has further complicated the problem of adequate coverage of the literature and has determined the present approach to the subject, which is intended to be illustrative rather than comprehensive.

Chapter VIII

EXPERIMENTAL METHODS FOR DETERMINING DISEASE INTENSITY-LOSS RELATIONSHIPS

There are many experimental methods that may be used in determining the effects of disease on plant yields, all of which are variations of three basic approaches: (a) producing disease or the simulation of disease and comparison of such plants with healthy control plants, (b) preventing disease and comparison with naturally infected control plants, and (c) finding diseased and healthy plants and comparing their yields. The choice of method depends to considerable extent on the nature of the disease. There is no one "best" method; each has its advantages and disadvantages. Often more than one method is used, in order to obtain confirmatory results by different techniques and to rule out the limitations of any one method.

Loss appraisal experiments have much in common with agronomic or horticultural yield tests, and the principles governing the work are similar. Both are quantitative procedures and are commonly conducted using similar planting and treatment designs, with statistical analysis of the results. It is well known in agronomic work that if a vigorous crop variety is planted adjacent to a less vigorous one, an exaggerated yield difference will be obtained, due to competition, the less vigorous plants being suppressed by the more vigorous ones. This effect is eliminated by various devices, such as triple-row planting of each crop variety with harvesting of the middle row for yield measurement. The same principle applies to loss measurement, since with adjacent diseased and healthy rows the former will be suppressed by the latter, exaggerating the loss from disease.

GREENHOUSE INFECTION EXPERIMENTS: -- This method consists essentially in infecting certain plants with disease under greenhouse conditions, leaving others uninfected or protecting them from infection, and comparing yields. Discussions of the use, advantages, and disadvantages of the greenhouse method are found in the works of NAUMOV (1939) and CHESTER (1944).

There are numerous advantages to the greenhouse method as compared with field methods of disease loss appraisal. In the greenhouse, loss determinations can be made under known, controlled conditions of light, air humidity, and soil moisture. The soil composition can be held uniform. The experiments can be protected from natural hazards which commonly interfere with field experiments, such as other diseases than the one under study, insect pests, rodents, birds, and unfavorable weather. In the greenhouse, attention can be focused on single elements of disease complexes, making it possible to analyze the role of each individual factor in the complex. Or, if desired, it is possible in the greenhouse to use definite combinations of factors, of controlled composition, as GREANEY and MACHACEK (1935) did in studying the effects of the foot rot fungus, _Helminthosporium sativum_, on wheat growth, with and without the presence of the harmless soil fungus _Cephalothecium roseum_.

Greenhouse work also gives the investigator much better control over the conditions of infection than he has in field experiments. He can use pure lines or individual physiologic races of pathogens in contrast to the mixed populations of pathogens in the field. He can inoculate plants at any desired developmental stage and produce any desired intensity of infection, or, as is preferable, he can produce a graded series of times and degrees of infection. Finally, there are some problems in loss appraisal which can be done most suitably or exclusively in the greenhouse, such as the measurement of losses in crops that are normally grown under glass, the study of the effects of noxious gases on plants, or the measurement of losses caused by diseases that are not yet widespread in nature, when it is unsafe to liberate them through field experiments.

Against these advantages must be listed the disadvantages of the greenhouse method. For crops that are normally grown in the field the greenhouse is a very abnormal environment. The outdoor conditions of light, moisture, wind, slope, exposure, and fluctuations of weather have no counterpart in the greenhouse, and as a result the field-grown plant is quite different (_e.g._, in the strength of its fibro-vascular system), the populations of disease organisms and hazard complexes differ, and, as a result, the course of disease, its tempo, is quite different in the field.

From these considerations one might expect that disease intensity-loss relationships will be different in greenhouse and field tests, and one might justifiably ask whether it is valid to use greenhouse data as a basis for estimating field losses.

A number of investigators have compared the results of greenhouse and field loss measurement tests. In some cases substantial disagreement has been found. PETURSON and NEWTON (1939) have pointed out that field experiments on cereal rusts often show a greater loss than greenhouse tests, because in the field rust damage is aggravated by water shortage, which does not affect greenhouse plants. GASSNER and STRAIB (1936) consider the opposite true, that greenhouse

experiments indicate more loss than actually occurs in the field. In a comparison of different methods for appraising loss from wheat leaf rust, the writer (CHESTER, 1946b, Fig. 2) found no material difference in the disease-loss relationships as determined by greenhouse and field methods. H. C. MURPHY (1935) also obtained similar determinations of loss from crown rust of oats in greenhouse and field experiments.

The study of the effect of leaf rust on wheat by MAINS (1930) is a good illustration of the use of this method. Numerous others have used it in studying cereal rust losses, including BEVER (1937), JOHNSTON (1931), PAL (1936), and RUSAKOV (1929c). The greenhouse method has been used in studying losses from tomato virus diseases by HEUBERGER and NORTON (1933), JONES and BURNETT (1935), and NORTON (1914), with downy mildew of onions by YARWOOD (1943), and in determining the effects of SO_2 fumes on barley and alfalfa by KATZ and LEDINGHAM (1939).

In using the greenhouse infection method any of the standard inoculation techniques are used: spraying or dusting plants with inoculum or applying it with a spatula, infesting the soil, or transmitting viruses by insects or mechanical means. The healthy control plants are uninoculated, and, if the disease is one that spreads naturally under greenhouse conditions, it may be necessary to protect them with fungicides or other means. Because of the uniform greenhouse environment, reliable results can be obtained with fewer plants in the greenhouse than in the field.

In summary, it appears that the greenhouse infection method is one of the more useful and reliable methods of determining disease intensity-loss relationships. Although its results frequently agree with those secured by field methods, this is not always the case, which indicates the desirability of supplementing greenhouse experiments with field tests in many instances. The greenhouse method has particular advantage in analyzing the loss from hazard complexes, and in some cases, such as the study of losses from crops normally grown in the greenhouse or of atmospheric injuries, it is the best method available.

FIELD PLOT OR BED INFECTION EXPERIMENTS: -- In using this method, disease is introduced into plants that are growing under normal cultural conditions, and the yields from the diseased plants are compared with those from comparable plots of uninoculated, healthy plants.

The chief advantage of the method lies in the normal growing conditions under which the experiment is conducted. The disadvantages are the converse of the factors listed as advantages of the greenhouse method, i.e., lack of control of numerous environmental and pathological factors. Outstanding among these is the natural occurrence of disease in the plots intended as healthy controls. Disease produced in the field by artificial inoculation is not always comparable to natural outbreaks. If the season is unfavorable for the disease the inoculation may only result in a short-lived, atypical attack.

There are several ways of dealing with these disadvantages. Disease may be prevented in the healthy control plots by treating these with fungicides, as was done by M. NEWTON et al. (1945) in studying the loss from barley rust. GASSNER and STRAIB (1936), who consider this the best of all methods of loss determination for cereal rusts, recommend having the inoculated plots widely separated from and on the leeward side of the healthy ones, with a neutral crop between, to prevent the disease from spreading to the healthy plots. This practice has the disadvantage of difficulty in having the two in strictly uniform environments.

In field tests of this sort it may not be possible to control the time, degree, and tempo of disease attack and, therefore, to study intermediate situations between two extremes. This is not always a limitation, however.

Virus diseases, for example, are of the "all or nothing" type, and here the time of infection is the important variable. This can easily be controlled and varied in field infection experiments, and tests of this sort have been used to advantage in investigating the losses caused by tobacco mosaic (McMURTREY, 1928, 1929; WOLF and MOSS, 1933; E. M. JOHNSON and VALLEAU, 1941) and tomato mosaic (HEUBERGER and NORTON, 1933).

In field infection tests, standard pathological and field experimental methods are employed. An approved plot design is generally used, to permit statistical analysis of the results. Inoculation of the plants is by any standard method, such as spraying or dusting the plots with bacteria or spores, introducing inoculum into the soil (root rot and wilt diseases), infecting plants before transplanting in the field (tomato and sweetpotato wilt), setting out infected plants at intervals in the plot to serve as sources of natural disease spread (cereal rusts), or inoculating individual plants by mechanical means (tobacco mosaic).

The study of GREANEY and MACHACEK (1934) on losses from cereal root rots is a good example of the method of field inoculation, illustrating the use of replicated plots, several techniques of soil infestation, and a well-devised system of grading disease intensity and correlating this with yields.

Besides the several studies referred to above, the field infection method has proven useful in investigating losses from sugar cane root rot (EDGERTON et al., 1937), tomato root knot nematodes (FICHT, 1939), flax rust (FLOR, 1941), potato virus diseases (FOLSOM, 1927; K. M. SMITH and MARKHAM, 1945), and sugar beet yellows (WATSON et al., 1946).

FIELD OR GREENHOUSE PLANTINGS WITH INOCULATED SEED: -- This method differs from the preceding two only in the fact that disease is produced by inoculating seed prior to planting, rather than inoculating the growing plants. It has found greatest usefulness with those diseases that are typically or exclusively seedborne.

The seed inoculation method has been successfully used in studying losses from bunt of wheat by FLOR et al. (1932), LEUKEL (1937), and KIESSELBACH and LYNESS (1939). The seed have been inoculated by dusting them with smut spores, and yields from plants produced by such seed have been compared with those from healthy plants. Different degrees of disease are obtained by varying the dosage of spores or by mixing inoculated seed with clean seed in different proportions. A similar procedure was followed by SEMENIUK and ROSS (1942) in their study of losses from loose smut in barley.

PLANTINGS FROM SELECTED DISEASED AND HEALTHY PROPAGATION MATERIALS: -- This method differs from the last only in the fact that the seed or parts used in vegetative propagation are not inoculated but are selected for presence or absence of disease. The method has been so extensively used in the study of losses from potato virus diseases that these are considered separately.

Potato Virus Diseases. -- The basic principle of this method with potato virus diseases is simplicity itself: to plant selected virus-diseased tubers and virus-free tubers and compare yields. Some 45 papers devoted to this subject have been consulted and these reveal a great variation in the details of conducting tests based on this principle.

To begin with, there have been various ways of selecting the diseased and healthy seed tubers. Most primitive, yet in a sense most convincing in demonstrating to growers the value of virus-free seed potatoes, is simply to take a random sample of tubers from a field that is heavily infested with virus diseases and a sample of high quality seed tubers, e.g., certified seed, and compare yields from plantings of the two. Here the "healthy" seed will contain some virus-infected tubers and the "diseased" seed may contain some relatively healthy tubers. Yet it is with such seed lots that the grower is practically concerned and the loss revealed to him by such a test more nearly expresses the virus hazard than comparison with the homogeneous diseased and healthy seed lots that are scientifically more desirable.

A similar purpose has been served by determining yields, year after year, of potatoes grown from stocks that have been rogued each year to remove virus infected plants as compared with yields from unrogued stocks. Here the "diseased" seedstocks are not 100% infected nor are the "healthy" stocks 100% healthy, but the situation is a practical one.

In much of the early work in measuring the losses from virus diseases in potatoes, the plants to furnish the seed tubers, both diseased and healthy, were selected in the field, the diseased plants having occurred naturally or having resulted from deliberate planting of diseased stock for this or other purposes.

This procedure brings the condition of the seedstocks under somewhat better control, since each parent plant producing the seed tubers has been inspected. It is not all that can be desired, however, for some plants that are rated "healthy" will usually be in early stages of infection, and the tubers from such apparently healthy plants produce diseased plants in the experiment the following year. Also, even a well-trained inspector sometime has difficulty in correctly classifying potato plants according to virus infection, especially when two or more viruses are present in the field. The "diseased" seed tubers, in this case, may not be homogeneous.

A more reliable technique is to plant relatively or absolutely disease-free tubers and inoculate some of the healthy plants produced with pure cultures of known viruses, leaving others uninoculated, and roguing out any plants showing natural infection. The tubers from the inoculated and uninoculated plants are harvested separately and used for planting the yield-loss experiment the following season.

A further refinement of the technique is to eye-index each tuber to be used in the loss test, as in the experiments of GARDNER and KENDRICK (1924, 1928). An eye from each tuber is planted in the greenhouse in sufficient time before the field planting to permit the experimenter to inspect the plant developing from the eye and determine virus infection. Each eye is identified with the tuber from which it was taken, and only those tubers with eyes that produce plants of the desired condition with respect to virus infection are used in the field experiment.

During recent years it has become apparent that practically all potatoes of numerous commercial varieties harbor the X-virus, latent mosaic virus, or "healthy potato virus", and that this virus, without producing noticeable symptoms, subtly reduces yields by 10% or more. This implies that in virtually all but recent studies the loss comparisons have not been between healthy plants and those with a single virus disease, but between plants with X-virus and plants with a second virus plus X-virus (K. M. SMITH and MARKHAM, 1945).

Two methods of avoiding this source of error and obtaining truly healthy plants have been used. E. S. SCHULTZ has developed a strain of potato that is immune from the X-virus, seedling 41956, and has used this strain (SCHULTZ and BONDE, 1944), with and without infection with other viruses, to determine the yield-depressing effects of the latter. BALD (1944) has solved the problem by developing and maintaining clones of potatoes free from the X-virus (FX), and using these in his tests. CLINCH and McKAY (1947) verified the condition of freedom from the X-virus in their similar clones by inoculating juice from each plant into Datura seedlings, in which the X-virus causes easily observed symptoms, though these are lacking in potato.

When a virus-infected tuber is planted, the plant that develops is subject to the effects of the virus throughout its entire life, in contrast to the healthy plant that becomes infected at some time during the growing season. It naturally follows that the loss produced by the virus is greater in the former case than in the latter, particularly if infection in the field occurs late in the growing season. In practice we are concerned with losses from both types of infection. The method of setting up experiments to measure the losses differs, in the first case consisting in planting infected tubers, which has been done in most of the work on potato virus losses, while the second case involves field inoculation experiments.

As brought out on page 229, the amount of loss varies with the strain of virus used, and the methods of measuring loss from potato viruses include consideration of this point, as is seen in the work of SCOTT (1941), BALD (1943b), E. S. SHCULTZ and BONDE (1944), and CLINCH and McKAY (1947).

In the early work on potato virus losses, the experiments were commonly on a small scale, involving comparisons of a few dozen hills and without replications (e.g., FOLSOM, 1920). A field design, if used, was usually a simple matter of planting adjacent rows with diseased and healthy tubers respectively (WHIPPLE, 1919; T. WHITEHEAD, 1924). Later, as the importance of analysis of experiments to determine statistical significance became recognized, the potato virus loss measurements have been based on replicated plantings in approved designs, as illustrated in the papers of BALD (1943b) and LECLERG et al. (1944).

Since, in actual practice, we do not deal with comparisons between totally diseased and totally healthy stands, but rather with varying percentages of diseased plants distributed at random among healthy ones, a number of the students of potato virus losses have designed their experiments with this point in mind. The percentage of diseased seed pieces was predetermined by mixing healthy and diseased ones in different proportions to produce a series of disease percents ranging between 0 and 100% in the experiments of BONDE and E. S. SCHULTZ (1940) and of LECLERG et al. (1944, 1946). Experiments set up in this fashion show that loss is not directly proportionate to disease percent, since healthy plants adjacent to diseased ones compensate for the loss in the diseased plants to some extent.

In deliberate efforts to avoid the phenomenon of compensation, P. A. YOUNG and MORRIS (1930) planted diseased and healthy tubers in alternating groups of four similar consecutive pieces, widely spaced to diminish the compensation effect, while McKAY and DYKSTRA (1932) accomplished the same end by planting in the same fashion at normal spacing, but harvesting, for yield measurement, only the center two hills of each group of four.

In complete contrast with this arrangement, KIRKPATRICK and BLODGETT (1943) planted diseased and healthy tubers in all possible arrangements of three consecutive hills in an effort to study the effect of compensation on virus losses. This is a more realistic approach to the problem, since compensation is a major factor affecting losses under normal field conditions. A more detailed account of this work, with citation of related papers, is given in the discussion of compensation on page 320.

Numerous other difficulties have beset the path of the student of losses from potato virus diseases, most of which have been overcome. A common shortcoming in the earlier studies has been the indefiniteness with which viruses have been identified, the term "mosaic", for example, referring to any of several diseases. This has been largely cleared up through the work of E. S. SCHULTZ and others.

Besides the X-virus, discussed above, other mild or symptomless viruses have sometimes affected the plants thought to be healthy, leading to incorrectly low loss measurements. This source of error is gradually lessening by use of virus-immune stocks, seedling stocks that have been protected from all viruses, indexed stocks, and better methods of virus identification.

A number of investigators have been unable to secure totally healthy stocks to compare with diseased ones and the comparisons have been between stocks with small and large percentages of disease. One way of dealing with this problem is to determine the yields of potato stocks with various amounts of virus disease, derive a formula for regression of yield on disease percent, and extrapolate to the 0% and 100% levels. Such a practice is illustrated in the work of KIRKPATRICK and BLODGETT (1943).

A constant problem in this type of study is the fact that potatoes tend to be infected with not one but several viruses simultaneously. This is desirable, in loss studies, in cases in which a definite mixture of viruses constitutes what, for practical purposes, is a single pathological condition or loss factor. This is true, for example, of rugose mosaic (X + Y viruses) or mild mosaic (X + A viruses). The problem appears, however, when the planting becomes a miscellaneous mixture of viruses, due to natural infections or use of uncontrolled seed stocks. This has been a fault in a number of the earlier studies, but is less so in more recent ones, in which practices mentioned previously have served to keep the stocks homogeneous.

Since potatoes are vegetatively propagated, they exist as clones. Their virus diseases being transmitted regularly through vegetative propagation, any two clones tend to differ from each other in two respects: (a) in their virus content and (b) genetically. If the yield of a clone that is generally infected with a given virus is compared with the yield of another clone that is relatively virus-free, the difference in yield may be influenced both by the difference in virus content and by genetic differences in the clones. This may introduce an error into loss determinations that can be avoided by using tubers of a single clone divided into two aliquots, one of which is infected with a given virus by inoculating the plants producing the infected tubers.

Potatoes are affected with certain troubles resembling viruses but apparently due to genetic defects, such as some forms of "giant hill" and "wilding". The foregoing remarks on determining losses from virus diseases in general apply to these genetic troubles, which are tuber-borne in the same fashion as viruses.

Other Diseases. -- The method of planting selected diseased propagation materials for comparison with healthy plants has also been used effectively in studying losses from other typically seedborne diseases, including loose smut of wheat (COMPTON and CALDWELL, 1946), barley stripe (SUNESON, 1946), sugar cane mosaic (EDGERTON et al., 1937), sugar beet mosaic (GASKILL, 1940), and potato scab and *Rhizoctonia* (COONS, 1918).

In the case of barley stripe, diseased and healthy seed were obtained from field plots some of which had been inoculated with the disease the previous year. With potato it was a simple matter of separating the diseased from the healthy tubers and planting under comparable conditions. Since beets for seed purposes are grown as biennial crops, the method here is to select diseased and healthy plants toward the close of the first season and plant these separately to compare seed yields in the second season. The case of sugar cane mosaic is very similar to that of potato viruses as already discussed.

COMPARISON OF YIELDS OF ROGUED AND UNROGUED PLANTINGS: -- Roguing, or removal of diseased plants, was mentioned as an adjunct to the method of selecting diseased and healthy progagation materials. We are concerned here with current-season roguing where this is the principal means of securing diseased and disease-free plots for comparison.

In studying losses from potato virus diseases, roguing the previous season to secure virus-free seed stocks has frequently been practiced, but only one reference has been found to current-season roguing for this purpose. This is in a paper by E. S. SCHULTZ and FOLSOM (1923), who planted strains of potatoes carrying given percentages of mild mosaic, rogued out the mosaic plants from a part of each planting. and then compared yields from the rogued and unrogued portions. Here a serious error is introduced by compensation in plants adjacent to the rogued-out hills, unless a similar spacing is used in the diseased plots.

The measurement of losses from bean mosaic, as studied by WALKER and JOLIVETTE (1943) consisted in planting commercial lots of bean seed and roguing out the diseased plants to secure healthy plots for comparison with diseased ones.

With the same disease, HORSFALL (in HARRISON, 1935) has carried this technique a step farther by using a practice which we may designate reverse roguing, one that is very effective in dealing with plantings in which 50% of the plants, more or less, are diseased. The partially diseased plantings are divided into multiples of two similar subplots. In one of each pair of subplots the diseased plants are rogued out and in the other the healthy plants are removed, an attempt being made to secure uniform stands of diseased and healthy plants respectively.

This technique has particular value when an excessive seeding rate is used and the roguing and additional thinning leave the diseased and healthy plantings with similar stands of a desired degree of uniform spacing.

This appears to be an ideal method of studying the effects of non-fatal damping-off on subsequent development and yields of plants, and has been so used, with good results, by STEVENSON (1947) in measuring losses from seedling diseases of castor beans.

THE CULTURAL METHOD: -- This involves a comparison of yields of relatively diseased and healthy crops, the disease occurring naturally, with the degrees of disease being due to differences in cultural conditions, such as different methods of soil management. Studies by this method are subject to serious error due to the fact that the cultural differences have direct effects on yield levels in addition to their indirect effects in increasing or decreasing disease. Yet in some cases this source of error can be minimized, and in any case data obtained by this method are useful in confirming the results of more accurate experimental procedures.

With different types of disease the error due to the direct effect of fertilizers on yield varies considerably. Working with the response of common root rot of wheat to phosphate fertilization, RUSSELL and SALLANS (1940) in a number of cases obtained significant or highly significant correlations between increasing disease and decreasing yield. The phosphate by itself increased yields to an extent great enough to offset the increase in disease associated with the fertilization. With the takeall root rot of wheat, fertilization increased the yield more than enough to offset the effects of the disease in the experiments of DOUGHTY et al. (1939). Complete fertilizer greatly reduced the amount of seedling disease and increased the yields of sugar beets, according to MORRIS and AFANSIEV (1945) but it is not evident to what extent the fertilizer alone was responsible for the increase in yields.

CHESTER (1946a) made an analysis of the loss caused by Fusarium wilt of cotton in relation to fertilization, based on the extensive data of V. H. YOUNG and his associates. This showed that when the disease was aggravated by soil deficiency, especially of potassium, the yield reduction was approximately twice that due to wilt alone, up to 25% wilt, while at higher wilt percentages most of the loss could be attributed to wilt alone. In this case the role of soil deficiency in reducing yields was determined approximately by subtracting the effect of disease alone from the effect of disease and soil deficiency combined. In case the disease data are from experiments in which loss is due to disease and soil deficiency combined, it should be possible to determine the effect of disease alone, in an approximate fashion, by subtracting the loss due to soil deficiency, acting alone in the absence of disease, from the loss due to deficiency and disease combined. This would be one way to rule out the error due to the direct effect of soil treatment, although no study using this method has come to hand.

A second method of escaping the error due to cultural treatment would be to assemble a sufficiently large quantity of data, based on a variety of treatments, to permit deriving the correlation between disease and loss regardless of treatment. This would be valid only if there was not a strong unilateral relation between treatment and disease intensity.

A similar approach has been based on the production of different amounts of disease by various cropping systems. Here there is also the danger that the cropping system itself has a strong direct effect on yield, but this is likely to be less than in the case of fertilizer experiments, since a major influence of crop rotations is on the disease, diminishing the inoculum potential of the soil, rather than directly on the plant and its yields.

AFANASIEV and MORRIS (1943) studied the amount of seedling disease and the yields in sugar beets grown in a variety of crop rotations, and their data show a fairly good regression of decreasing yield on increasing disease when all rotations are combined. Similar findings for cotton root rot have been reported by DUNLAP et al. (1940). Both investigations reveal the value of this method of appraising loss due to soilborne diseases. HOLBERT et al. (1919) have extended the use of the method to losses from wheat scab.

Finally, the cultural practice associated with different levels of dryland foot rot of wheat was date of planting in the work of ROBERTSON et al. (1942). Their study brings out strikingly the limitation of the cultural method except as an adjunct to other techniques of loss determination. It showed that with plantings up to September 15, in Colorado, planting data influenced yield due to its effect on disease, while in later plantings the seeding date influenced yield independently of disease.

THE INDIVIDUAL METHOD: -- This procedure consists in selecting from a planting a given number of diseased plants and a like number of healthy plants, and comparing yields.

The method has certain advantages. It may be applied in any non-experimental planting where any ratio of healthy and diseased plants may be found. This gives the method particular value when the observer has not laid out experiments for measuring loss, but accidentally encounters a planting containing disease, in which it appears desirable to know the amount of loss. There is also an advantage in using this method to measure losses from diseases which cannot readily be pro-

duced experimentally under conditions resembling natural occurrence, such as corn smut or Texas root rot, and diseases which require many years to develop to the stage in which the observer is interested, as in wood decays or long-standing cases of virus disease in trees. This is a basic method in forest disease appraisal.

Even when a disease can be produced experimentally, the selection of individual plants with different stages or conditions of disease may give the observer a greater variety of categories of disease from natural occurrence than would result from the more uniform conditions of an infection experiment. Advantage has been taken of this fact in using the individual method to study loss in relation to duration of infection (virus yellows of cherry), relative position of healthy and diseased plants in the row (potato viruses), and type, position, and developmental stage of lesions (corn smut).

This method is indicated when the object is to make a thorough and time-consuming analysis that must be limited, for practical reasons, to very few plants, in which case the individuals to be analyzed are selected with great care, as in the experiments of STONE (1936) on the growth, chemical composition, and efficiency of normal and mosaic-diseased potato plants.

Instead of comparing whole plants, their organs may be compared by the individual method. An example is found in the study of losses from pigeon pea anthracnose by TUCKER (1927) in which healthy and diseased pods were sorted out, shelled, and the yields of marketable peas compared.

When healthy and diseased plants occur spontaneously the occurrence of diseased plants (a) may be due to chance or factors quite unrelated to yield, or (b) may be associated with genetic or environmental factors which themselves influence yield while determining the occurrence of disease at the same time. As examples, the question of which trees in an otherwise uniform orchard become virus-infected and which ones remain healthy is largely or entirely a matter of chance, in which the disease is the only yield factor distinguishing the affected trees, as a group, from the healthy ones. On the other hand, certain root and foliage diseases tend to be concentrated in low spots in the field because of the higher soil moisture and poorer air drainage in such spots. If the yields of diseased plants in the low spots are compared with those of healthy plants on higher ground, yield differences will not be due to disease alone, but also to the direct effects on yield of the distinct soil, moisture, and aeration conditions in the low areas, contrasted with the higher ones. Similarly, one plant may be diseased and another healthy because they differ genetically. But if there is a difference in genetic constitution, shown in a difference in disease susceptibility, there also may be genetic difference in yielding ability in the absence of disease, and a difference in yield will then be due, not to disease alone, but to disease and inherent yielding ability combined. It follows that the individual method will be most useful and reliable in appraising diseases in which infection differences are due principally to chance and not to differences in environment or genetic constitution of the plants.

In using the individual method it is common to compare healthy plants surrounded by diseased ones with diseased plants surrounded by healthy ones. This is just the opposite of infection experiments in which a deliberate effort is usually made to compare yields of plants surrounded by others of the same pathological condition. An objection to the individual method has been raised by FOLSOM (1927) who pointed out that the effect of a disease on yield is exaggerated when a diseased plant is grown in competition with healthy ones. This is true, yet it represents a natural situation; in nature, except in cases of 100% infestation, diseased plants normally are in competition with healthy ones, and loss so measured corresponds most closely to the loss actually experienced in practice. It is often desirable, however, to measure absolute loss under conditions of freedom from competition with healthy plants. It follows that there are uses and values in both types of tests, and that the individual method is not objectionable because it is used to measure loss under conditions of natural competition, but on the contrary its value is enhanced by this fact. Special studies on disease and compensation, using the individual method, are discussed in connection with compensation on page 320.

The individual method has found use in determining the losses caused by virus diseases of potato, cowpea, soybean, sugar cane, stone fruits, and citrus, cereal root rots and rusts, Texas root rot in cotton, Fusarium wilt of potato, and corn smut.

The latter case deserves particular mention since in dealing with corn smut we find the individual method highly developed and almost exclusively used. The basic practice is to select healthy and naturally smutted corn stalks and compare yields. To secure most comparable results it is customary to select the plants by pairs, the diseased and healthy member of each pair being in the same hill, adjacent plants one foot apart, or up to three hills apart, in the practice of different workers. The smutted stalks have usually been subdivided into classes depending on the position, size, and number of smut boils per stalk.

The same principle of using paired diseased and healthy plants extends to other types of disease, as in studies of losses from cereal root rots and of virus yellows of cherry. The use of paired plants is an attempt to secure diseased and healthy individuals that are fully comparable except for the condition of disease. Sometimes a conscious effort is made to select plants that appear to the observer to be comparable. KOTILA (1923) mentions his effort to secure mosaic diseased and healthy potato plants with the same number of stems and of equal vigor. This is a questionable practice; it is highly subjective, since the observer usually does not know the extent to which the disease has made the plants non-comparable, i. e., has reduced the number of stems or decreased the vigor of the plants. A safer procedure would be to select the healthy plants to compare with diseased ones by some arbitrary formula, as was done in most of the corn smut studies, although one must not disregard the necessity for selecting plants that are comparable in respects that are quite independent of the disease (plants in similar soil, trees of similar age, etc.).

For convenience it is a common practice to indicate selected plants by stakes, at the time when the disease is best apparent, to aid in locating them at harvest time.

The study of loss from common root rot of wheat made by SALLANS and LEDINGHAM (1943) is a good example of use of the individual method. A series of paired diseased and healthy samples, each consisting of a square yard area with the two members of the pair not more than 4 to 5 feet apart, were used for disease appraisal and yield measurement. Disease was scored according to lesions on the crown and subcrown internodes, and the yield data included both gross yield and kernel weight.

THE TOPOGRAPHICAL METHOD: -- This is a variant of the individual method in which the samples, instead of being single plants or very small plant groups, are more extensive populations differing in disease intensity because of environmental factors associated with differences in terrain or because of differences in exposure to disease inoculum, although comparable in other respects, such as variety, time of sowing, and cultural practices.

Studies by this method are particularly subject to the criticism that variations in terrain bring about differences in yields quite apart from the effects of disease. The method has been used in Russia (NAUMOV, 1939) in studies of cereal rusts, where it is felt that the method is promising but needs more methodological study.

A special case is that in which the amount of disease is not due to configurations of the land but to distance from a source of infection, conditioned by exposure to wind-blown inoculum. This method was used by RUSAKOV (1926) in studying losses from crown rust of oats, where the differences in disease were associated with distance from a protective forest strip and bushes of the rust's alternate host, the buckthorn.

COMPARISON OF FIELDS WITH DIFFERENT AMOUNTS OF NATURAL INFECTION: -- This is an extension of the individual method, comparing fields rather than individual plants in a single field. As with the individual method, different amounts of disease in different fields result from variations in soil, exposure, and microclimate, and, in this case, also from differences in crop variety, cultural practices, and macroclimate. Here, too, the method is most valuable with those diseases which occur by chance or are not unilaterally associated with ecological factors that in themselves strongly affect yield.

This extensive method lacks the accuracy of more intensive ones, but its reliability may be strengthened by several means. One is the use of so many fields that their differences, other than disease, tend to cancel out one another, leaving the disease statistically as the most important yield factor. Using this method, HORSFALL (1930) examined 195 fields of meadow crops in 35 counties, WIANT and STARR (1936) studied 125 fields of alfalfa, and WALKER and HARE'S (1943) survey for pea diseases involved 654 fields, many of them being examined twice.

A second method of increasing accuracy, which is just the opposite of the first, was used by EZEKIEL and TAUBENHAUS (1931, 1932, 1934) who made a 12-year study of yields from two adjacent cotton fields, one of which was infested with Texas root rot, but which were otherwise very similar and comparable.

The general procedure in studies of this kind is to classify each field according to disease intensity, secure a record of the yields actually obtained, and determine the regression of yield on disease intensity.

MACHACEK'S (1943) determination of the loss from wheat root rot in Manitoba is a good illustration of this method, with the only variation that instead of taking acre yields for entire wheat fields his yield measurements as well as disease intensity records were based on samples of one meter of row taken at harvest time. The three-year study involved 60 fields, 10 in each of six soil type zones, with 10 samples per field. From the data obtained it is possible to plot a regres-

sion showing that for every increment of 10% of root rot there was approximately 3% crop loss.

The lack of accuracy in this method is compensated for in considerable degree by its extensive nature, giving the observer a picture of loss over a broad area instead of in a few experimental plots. The method has value in numerous cases and particularly in confirming and extending the results of more intensive studies.

COMPARISON OF YIELDS OF DISEASE-RESISTANT AND -SUSCEPTIBLE CROP VARIETIES: -- On first consideration an excellent method of determining loss from disease would appear to be a comparison of yields of varieties that are resistant to the disease with yields of susceptible varieties and expressing the difference in yield as percent of crop loss from the disease. Reference has already been made to this approach in connection with the historical method of determining loss from disease (p. 284), where it was seen that the introduction of disease-resistant varieties of certain crops, such as wheat, sugar beets, and sugar cane, so improved the yields by reducing the loss from disease that the economics of growing the crop was radically altered.

This method may involve comparisons between yields of resistant and susceptible varieties in small, uniform, replicated plots, or it may deal with large acreages or even great regions, or the two may be combined as in CRAIGIE'S (1944) analysis of wheat losses from stem rust in western Canada. If small plots are used there is the advantage that the work in loss determination may be carried on at the same time and using the same materials as routine variety tests, such as are conducted at every agricultural experiment station. In these tests it is customary to plant assortments of resistant and susceptible varieties under conditions that favor accurate yield determinations, which are regularly taken. For the additional purpose of loss determination it is a simple matter to appraise the disease intensities on these varieties and to analyze the yield data in relation to disease intensity.

The most serious source of error in this type of test lies in the fact that different varieties of any crop tend to differ in innate yielding ability in the absence of disease. If, in the presence of disease, a resistant variety outyields a susceptible one, the yield difference due to disease alone is increased or decreased by the inherent difference in yielding ability. Quite a number of the crop varieties recommended for disease resistance are inferior to the older, susceptible varieties in innate yielding ability, as is commonly seen in cases in which the susceptible variety outyields the resistant one unless disease is present, when the reverse occurs. A good example is Ladak alfalfa, which yields more than the common varieties only in the presence of the bacterial wilt disease. In such a case the disease loss determined from the difference in yield of resistant and susceptible varieties would be underestimated. There are also cases of the opposite sort, that would lead to overestimates of loss. When a disease is catastrophic in character, however, as with sugar beet curly top, Granville wilt of tobacco, or powdery mildew of cucumbers, the loss from the disease so overshadows all other yield factors that the difference in yield between resistant and susceptible varieties approximates the true loss caused by the disease.

Fortunately there are several good methods of minimizing the error due to other yield factors in tests of this sort. These methods are described in the following subsections. Another source of error is less easy to overcome; namely, the fact that resistant varieties usually are not wholly immune from the effects of disease, but suffer some loss, as has been well brought out for wheat leaf rust by MAINS (1930). This has the effect of lowering the observed loss from disease below its true level. When totally resistant varieties are not available, perhaps the best way of dealing with this source of error is to measure the small amount of disease loss in resistant varieties by comparing their yields in the presence and absence of disease, and then use the findings to correct the loss values derived from comparing yields of these resistant varieties with yields of susceptible ones, in the presence of disease.

Correction For Other Yield Factors By Use Of Large Numbers Of Varieties. -- In using variety test data for determining the effect of disease on yield, the error due to other yield factors than disease reaction in the varieties may sometimes be eliminated by using a large number of varieties, with the assumption that there is no constant correlation between disease reaction and some other factor of importance in influencing yields. This assumption is not always warranted; in the case of corn smut, for example, in many varieties there is a correlation between smut resistance and low vigor. In such a case little difference might be seen between the yields of smut-free but less vigorous varieties and smutted but more vigorous ones. Yet in some instances this appears to be a valid approach to the problem of determining loss from disease.

An illustration of this procedure is seen in the work of GOULDEN and ELDERS (1926), who compared 146 wheat varieties, found a negative correlation between yield and attack by leaf and stem rusts, and were able to express this relationship by regressions showing the loss in yield due to increments of rust from 4.5% to 94.5%. The work was somewhat handicapped by the fact that the two rusts occurred together on the same plants. SALMON and LAUDE (1932) worked out

a similar problem in the same manner, using 25 wheat varieties that differed in reactions to leaf rust and speckled leaf blotch. When the wheat varieties were arranged in descending order of yield, they were found to be in ascending order of disease, and this was particularly true when the two diseases were combined into a single infection index.

CHESTER (1946a) has analyzed a large body of data on cotton wilt and yields, amassed by V. H. YOUNG and his associates. In this case other yield factors than wilt reaction evidently cancelled out one another when many varieties were classified by wilt percent, so that the latter showed a well-fitting linear relationship with yield, each 5% of wilt resulting in a 3% yield reduction (l. c., Fig. 1).

Correction For Other Yield Factors By Using Varieties That Are Similar In Other Respects Than Disease Reaction. -- Loss due to a disease may be reliably determined if we compare the yields of two varieties that differ, for practical purposes, only in reaction to the disease. This was the procedure followed by WALDRON (1928) in comparing yields, under conditions of rust exposure, of the susceptible variety Marquis and the comparable but resistant variety 1656.85. Various rust intensities on Marquis wheat were obtained in different localities, and the regression of yield on rust was approximately a straight line, from which it was possible to calculate the approximate loss from rust in each of four regions of North Dakota, and for the State as a whole.

Correction For Other Yield Factors By Comparing Varieties In the Presence And Absence Of Disease. -- If varieties that are resistant and susceptible to a disease have equal yields in the absence of disease but unequal yields, in favor of the resistant variety, on exposure to disease, this inequality may be taken as a measure of the loss caused by the disease.

Somewhat more subject to error, but nevertheless to be considered as of some value, is to use resistant and susceptible varieties that differ in yielding ability to a given, constant degree, under disease-free conditions, comparing their yields when exposed to disease. If, for example, variety X regularly outyields resistant variety Y by 10% when the two are not exposed to disease, while variety Y outyields X when the latter is diseased, we may regard the difference in yields, corrected for the inherent difference in yielding capacity, as a measure of loss caused by the disease.

This procedure is subject to the theoretical objection that the equality or difference in yielding ability under disease-free conditions may not exist under the particular environment that favors disease. To illustrate, a resistant and a susceptible variety might yield equally well under the dry conditions that inhibit a certain disease, yet one of these, let us say the disease-susceptible one, might differ from the resistant one in being able to make more efficient use of abundant moisture. When the two are exposed to disease, the yield of the susceptible variety, relative to the resistant one, is subject to two contrary influences: decrease because of the disease and increase because of greater efficiency in water utilization. It could even happen that the two influences would offset each other, in which case the resistant and susceptible varieties would yield equally well whether or not disease was present, and one would be led to the false conclusion, from this procedure alone, that the disease has no yield-depressing effect.

This theoretical objection could be validated or rejected by the simple expedient of using a chemical method of disease control under the conditions favoring disease, to determine whether and to what extent there actually may be a difference in relative behavior, reflected in yields, of the two varieties under the two environments, one favoring and the other inhibiting the disease.

Two examples of the use of this method may be cited. WELLHAUSEN (1942) reported that the leaf blight resistant corn, Hybrid 939, which outyielded the very susceptible Ohio W-17 by 2.5 bu. per acre during five years of minor disease, also outyielded the Ohio W-17 by 2.5 bu. per acre during a year of severe leaf blight (Helminthosporium), which was interpreted as indicating that this disease has little effect in lowering yields. In contrast, H. C. MURPHY and BURNETT (1943) compared the average yields of three oats varieties that were resistant to crown rust with those of three susceptible varieties; the resistant varieties outyielded the susceptible ones by 7 to 10% during three years when there was little or no rust, by 27% during a year of severe rust, and by 61% during a year of very severe rust, which is indicative of the serious losses caused by this disease. In neither of the two cases cited were data submitted to show whether the difference in yield response under the presumably moister conditions of the disease years was the same as that observed in the disease-free years, apart from the disease effect itself. Inclusion of sprayed plots of the susceptible varieties in the experiments would have answered this question.

COMPARISON OF YIELDS OF RESISTANT AND SUSCEPTIBLE SELECTIONS FROM A SINGLE CROP VARIETY: -- It not infrequently happens that in an apparently otherwise uniform crop variety there will be found individual plants that differ strikingly in their reactions to a given disease. The writer found, for example, that while Westar wheat in general is susceptible to race 21 of leaf

rust, a small percentage of plants that are otherwise typical for Westar were highly resistant to this race. Comparison of the yields of such resistant and susceptible lines when exposed to disease gives a measure of loss that is relatively exempt from criticism, since, apart from disease reaction, the lines are strictly comparable. Yet, even here the objection may be raised that the resistant and susceptible lines may differ physiologically in other respects than disease reaction, though alike morphologically. This objection could be answered by simple experimentation.

The advantages and limitations of this method, as used in measuring losses from cereal rusts, have been discussed by NAUMOV (1939) and CHESTER (1944). An illustration of use of the method is seen in the work of S. F. ARMSTRONG (1922) with stripe rust of wheat. He found that the variety Jap contained morphologically similar strains that differed in rust susceptibility, and a comparison of these brought out a yield reduction of 48.8% caused by this disease under specified conditions.

COMPARISON OF YIELDS OF RESISTANT AND SUSCEPTIBLE SEGREGATES FROM HYBRIDIZATION: -- This method, which is very similar to the preceding one, is based on the assumption that a group of disease-resistant lines from a resistant x susceptible cross will differ from a group of susceptible lines from the same cross principally in disease resistance alone; the larger the numbers of such lines used, the greater will be the probability that this is true, and that there will be a high correlation between disease differences and yield differences. An objection to the method is the theoretical possibility of genetic correlations of such a nature that disease reaction and some other factor of yield importance do not segregate independently; there is no evidence, however, that this has been a fault in the majority of experiments of this type.

Genetic segregates have been used in studying losses from the cereal rusts in the United States (IMMER and STEVENSON, 1928; WALDRON, 1936; JOHNSTON, 1937, 1938) and in Russia (LUKYANENKO, 1934; SHEVCHENKO, RUSAKOV, PANCHENKO, and PRONICHEV, cited by NAUMOV, 1939, in his discussion of this method). The method is well illustrated in IMMER and STEVENSON'S biometrical study of factors affecting yield in oats, making use of 280 selections from two crosses, with the relation of rust to yield seen in partial correlations. LUKYANENKO grouped 197 wheat lines from six crosses between resistant and susceptible parents into three classes, showing 0-5%, 25-40%, and 65-100% leaf rust intensity respectively. The least infected group exceeded the most heavily infected group in grain yield by 26.7%, with high statistical significance, and the group of intermediate rust susceptibility was also intermediate in yield.

Chapter IX

EXPERIMENTAL METHODS FOR DETERMINING DISEASE INTENSITY-LOSS RELATIONSHIPS (Contd.)

COMPARISON OF YIELDS OF A SUSCEPTIBLE VARIETY WITH AND WITHOUT PROTECTION WITH PESTICIDES: -- This major method of determining the amounts of loss caused by plant diseases basically involves a comparison of yields of two plots of the same disease-susceptible variety, exposed to disease, in which the plants of one plot have been protected from infection by a pesticide. Entomologists have made extensive use of experiments of this sort, using insecticides to protect plots. Standard field plot techniques, with an approved plot design, replications, consideration of border effect, and analysis of the significance of the data obtained are integral elements of this method of disease appraisal.

Pesticide experiments are most commonly conducted for the purpose of developing practical disease control practices. The data from such tests, though not conducted with loss appraisal in mind, frequently may be used for this purpose provided they include accurate information both on disease intensity, in check and treated plots, and on yields of both. Unfortunately, however, the data from many pesticide experiments aimed at disease control cannot be used for the purpose of loss appraisal because of the lack of records of either disease intensity or yields.

For convenience, the following discussion is divided into sections on seed treatment experiments, spraying and dusting trials, and soil treatment, with consideration of the possible effect of pesticides on yields apart from their action in controlling disease.

Seed Treatment Tests. -- Determining disease loss by comparing yields from disinfected versus untreated seed has found its greatest usefulness in studying the losses caused by seedling disease or damping-off, although it may also be used with such typically seedborne or tuberborne diseases as the cereal smuts or potato scab and Rhizoctonia. In the latter cases, however, loss from disease has been more commonly measured by other methods, such as the comparison of yields from plantings of diseased and disease-free seed or tubers.

Consideration of loss from seedling disease at once leads us to the relationship between stands and yields, a question that will be discussed at a later point (page 318). It has long been customary to avoid the losses from seedling disease by using an excessive seeding rate, such that many plants can be sacrificed without loss of a satisfactory stand. In the culture of cotton, before the adoption of seed treatment, it was customary to plant ten times as many seed as were expected to produce plants that would grow to maturity. Many of the untreated seed rotted in the soil, others produced seedlings that damped-off, and the survivors were thinned or "chopped" to a tolerable stand. The height of misunderstanding of this situation is seen in a statement of a former cotton-state governor, who edified his constituents by telling them that the 90% excess seed planted have the purpose of fertilizing the surviving 10%.

If it is true that this practice of overplanting and thinning the survivors does result in a normally-spaced and healthy stand, the loss from damping-off is simply the cost of the excess seed and of thinning. There are several common situations where this is not true, however. Damping-off from untreated seed is sometimes so severe that no useable stand is obtained. Here the loss includes the total cost of seed and seeding, use of the land when it is accomplishing no useful purpose, and the additional losses from replanting at a later, less favorable date, with production of a late crop, harvested when low late-season prices prevail. Even if a tolerable stand is obtained it is usually an uneven one; some plants are widely spaced and others are close together, resulting in some decrease in possible yield due to crowding and incomplete ultilization of the soil. Finally, even if an overplanted crop has withstood the ravages of damping-off enough to produce an even stand of plants that grow to maturity, it is now becoming clear that many of the survivors are subnormal; they never entirely recover from non-fatal root and stem injuries initiated in the seedling stage. This last point is illustrated in one of McNEW'S (1943e) tests of pea seed treatment, in which there was only 1% difference in stand from treated and untreated seed, yet the treated seed produced plants that outyielded those from untreated seed by 9%.

The seed treatment method poses certain problems in assessing disease intensity. The treated plots are seldom 100% healthy and the untreated ones may produce fairly good stands. Such differences in stand as do result are often not conspicuous, and the differences can be brought out only by replicated countings. These give little indication of the non-fatal injuries that may affect the plants. The differences in emergence may be miminized if the stands are thinned, the healthier stands being thinned more heavily than the diseased ones, and if it is the customary practice with the crop concerned, the plots must be thinned to give results that can be applied to agricultural practice. Yield losses from damping-off are most evident when the experimenter "plants for a stand" and does not thin, but this is not consistent with usual cultural practice with

such crops as cotton, corn and sugar beets.

In much of the seed treatment work the aim has been to determine the value of treatments and not to measure loss. Data from such experiments can sometimes be used in deriving loss even though this was not an objective of the experiments. Usually a number of different treatments have been used, and a comparison of yields of untreated versus the "best" treatment comes closest to a measure of loss, even though the "best" treatment does not produce perfect stands of entirely healthy plants. With sufficient data the theoretical yield of a perfectly healthy stand can be determined by extrapolation.

The following example, based on the sugar beet seed treatment data of AFANASIEV and MORRIS (1942), illustrates the method. The yield data for 3 seed treatments x 3 replications x 16 fertilizer treatments x 2 years were grouped into disease classes, averaged, and yield was plotted against percent of seedling disease to give the scatter diagram and regression shown in Figure 22. This regression shows that for every increment of 5% disease there was a loss of approximately 0.6 tons per acre or 3.5% loss of the potential crop, if free from seedling disease, which last, 17 tons per acre, was obtained by extrapolating the regression line to the zero disease point.

The seed treatment method is sometimes used in combination with other methods of loss appraisal; it may be combined with the method of comparing yields from diseased and disease-free seed as in LEUKEL'S (1937) work with bunt of wheat, or with roguing or reverse-roguing practices. In making use of seed treatment data for studying loss it is often necessary to consider environmental variables, such as temperature, moisture, and soil fertility, which can markedly affect the disease-loss ratio.

Sulfur Dusting Of Cereals. -- The most outstanding example of measuring disease losses by comparison of protected with unprotected plots has been in connection with losses from the cereal rusts as shown by sulfur dusting experiments. The use of fungicides against rusts goes back a half century to the work of BOLLEY, KELLERMAN, PAMMEL, GALLOWAY, and HITCHCOCK and CARLETON in the United States, COBB in Australia, and ERIKSSON and HENNING in Sweden. These early scientists were interested in rust control rather than loss measurement, but their work paved the way for what was to follow. Beginning in 1926 trials with sulfur dusting showed this to be a valuable aid in measuring loss from the leaf and stem rusts and powdery mildew of cereals, and this led to a series of important studies by CALDWELL, MAINS, JOHNSTON, and many others, in the United States, Russia, and Australia, and especially by GREANEY and his associates in Canada.

It was these experiments that first brought out clear-cut and irrefutable evidence that the losses caused by some of these diseases, notably leaf rust of wheat and powdery mildew of wheat and barley, were very much greater than had been recognized earlier, and that the existing estimates of the losses caused by these diseases were far too low. The literature on this subject has been reviewed, with citation of the important papers, by CHESTER (1946b), and, with special reference to Russian work, by NAUMOV (1939) and CHESTER (1944).

While the sulfur dusting method has many advantages, it also has possible limitations. It can be applied only to those diseases that are controllable with sulfur, e.g., it would not be suitable for bacterial leaf diseases of cereals. Control, when it is obtained, may not be complete, i. e., the comparison is between more and less diseased plants rather than between diseased and healthy ones. It frequently happens that two diseases both controllable by sulfur may occur together, in which case the findings relate to the loss from two or more diseases combined, and not to an individual disease. These last two limitations, fortunately, can be overcome by such device as extrapolation to obtain theoretical yields of totally healthy plants, and by using crop varieties that are resistant to other diseases than the one under study.

A very important theoretical objection to this method is that the sulfur may have some direct effect influencing yield (fertilization, toxicity) apart from its indirect effect in controlling disease and this possible objection is considered in a separate section below.

The methods of sulfur dusting experiments with cereals vary considerably in detail. Account of these methods, at some length, are to be found in the works of GREANEY (1933b, 1934) and CHESTER (1946b).

Although some of the earlier workers and the Russians have used flowers of sulfur as a cereal fungicide, the later and better investigations have involved use of the finer sulfurs that are manufactured expressly for plant dusting. PHIPPS (1938) in Australia used sulfur sprays. Depending on plot size, various types of dusting equipment have been used, including hand dusters, horse- or tractor-drawn or self-propelled ground dusters, and dusting airplanes.

A problem in this type of work is preventing the drift of the fungicide from the treated to the untreated plots. In small plot tests this has been diminished to unimportance by using dustproof screens to separate the plots during the dusting operation. With larger plots, the problem of

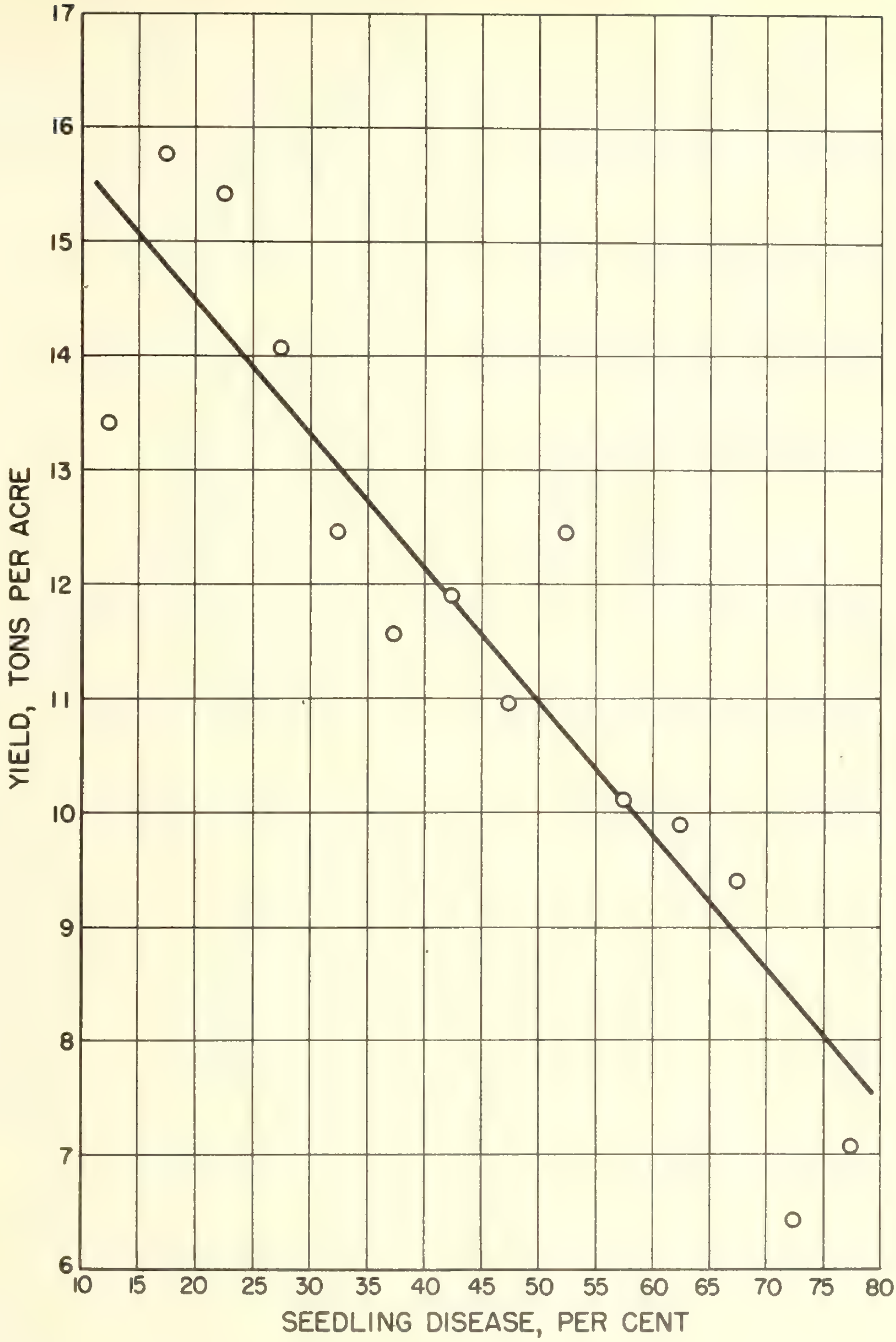


Figure 22. Regression of sugar beet yields on seedling disease. (From data of AFANASIEV and MORRIS, 1942.)

drifting dust is reduced by applying the dust during periods of calm air, locating the plots of untreated plants on the windward side of the treated ones, with reference to the direction of prevailing winds, and separating treated and untreated plots with strips of neutral plants. If the neutral plants are of a tall-growing species, they will also serve as dust screens.

The time, rate, and frequency of dusting have varied widely with different workers and different purposes of their experiments. For studying loss, an objective is to secure plants that are as nearly disease-free as possible, and this calls for earlier and more frequent dustings than would be desirable for an economical degree of practical disease control. There is a common tendency to begin dusting after disease is well established, and this inevitably results in "healthy" plants that are somewhat diseased. Much of the work on cereal dusting has been aimed at control of stem rust rather than leaf rust, which develops earlier in the season. As a result, the dusting schedules have begun later than is desirable for determining losses from both diseases. For controlling cereal rust in loss studies, a thorough schedule would be to begin dusting as soon as the first rust pustules can be found, even though the crop is still in the rosette stage, keeping the new growth protected by sulfur applications at 5 to 7 day intervals until maturity of the crop; this requires many more applications than would be justified for practical rust control. The usual rate is 15-45 lbs. per acre per application, with preference for the higher rates in loss studies. Dusting is most effective if applied before rains, and more frequent applications may be necessary during periods of protracted rains.

The cereal rusts are particularly favorable diseases for this method of loss appaisal because there already exist well-tested, standarized methods for scaling rust intensity, and for designing cereal field experiments, taking yields, measuring qualitative as well as quantitative aspects of loss, and analyzing the data for statistical significance. Replicated field plots for this work range in size from triple rod rows to strips of 1/40 acre or much more if dusting is by airplane. Good examples of the methodology are found in the works of BROADFOOT (1931), CALDWELL et al. (1934), GOULDEN and GREANEY (1930), GREANEY (1933b, 1934), GREANEY et al. (1941), JOHNSTON (1931), MAINS (1930), H. C. MURPHY (1935), M. NEWTON et al. (1945), and PETURSON and M. NEWTON (1939). GREANEY'S papers illustrate how the results of sulfur dusting experiments may be extended to appraisal of loss from cereal rusts over large territories.

The sulfur dusting method may be used to advantage in combination with other methods of determining losses, particularly the use of disease-resistant varieties to eliminate complication with other diseases than the one under study and to measure the direct effect of sulfur on plant growth, and the use of artificial disease inoculation methods to secure the heaviest possible infection on the undusted plants.

Spraying And Dusting Other Crops. -- In general the same principles apply here as were brought out in the preceding section. Spraying has an advantage over dusting in the fact that there is less drift to adjacent plots with sprays, which reduces the problem of eliminating fungicide deposits on untreated plots. The principal limitation of the method is the well-known direct effect of fungicides on yield, apart from disease control, discussed in the next subsection.

In work of this kind it is necessary to conduct controlled experiments. It is not sufficient, for example, to determine loss by comparing the yields obtained by growers who spray with those of growers who do not, since the grower who takes the trouble to spray usually follows other desirable practices, such as fertilization of soil, that independently increase yields.

The results from small-plot experiments sometimes indicate less loss than actually occurs, i.e., less difference in yield between sprayed and unsprayed plots, because the former, being near the latter, are subject to a higher inoculum potential than when large fields or orchards are sprayed or dusted, with no infected plants nearby. This source of error can be controlled, however, by relating yield reductions to degree of disease intensity, which is likely to be greater in treated small plots than in large treated areas.

When several types of treatment are used in the same experiment, the truest measure of loss is expected to be the difference between the "best" treatment and untreated control plants, but judgment must be exercised here since the "best" treatment, the one resulting in highest yields, may be stimulating to the crop in some other way than by controlling disease. Even the "best" treatments frequently do not give 100% disease control, and therefore measure relative but not absolute loss, a problem that can be overcome by analysis of the yield data in terms of degrees of disease intensity. Another principle that has been brought out by spray experiments is that the amount of loss, in absolute or relative terms, is greater for a vigorous, strong crop than for a crop that is growing poorly for any reason, as shown by BEAUMONT and LARGE (1944) for potatoes.

A particular advantage of this method lies in the fact that there exists a large body of data, from many sources, on the effects of spraying and dusting of various crops. Although many of

these data have little value in loss appraisal because they give no useful information on disease intensities, there are many other bodies of data that were obtained from the viewpoint of testing disease control measures, yet are sufficiently complete to be equally useful in loss appraisal since they meet the triple requirement of providing information on disease intensities, stage of development of the crop when exposed to given amounts of disease, and yields.

A few representative bodies of data on disease control by spraying and dusting have been analyzed in the present study, to illustrate the value of such data, but no attempt has been made to sift through the voluminous literature on spraying and dusting of fruits, vegetables, and other crops to glean information on the amounts of loss revealed by these tests. This remains a task for the future that may best be done by those with special interests in individual crops and diseases.

In a number of cases spraying or dusting experiments have been conducted with the specific objective of determining the losses caused by given intensities of disease at stated growth stages, often with analysis of the qualitative as well as the quantitative features of loss. Particularly good examples of this are M^c^NEW'S (1943a, f-j) studies on losses from tomato diseases. The spraying and dusting experiments to control celery leaf blights, made by NELSON (1939), NELSON and LEWIS (1937), TOWNSEND (1942), TOWNSEND and HEUBERGER (1943), and WILSON (1944), illustrate bodies of data that were not obtained with the intention of using them for loss appraisal, but are nevertheless so well documented that they are suitable for this purpose. In the celery work a particularly praiseworthy effort has been made to state disease intensity in concrete, standardized terms. It would entail little extra work, would increase the value of reports from the standpoint of disease control, and would make an important contribution to the knowledge of disease losses if, in the future, investigators conducting spray or dust trials would report disease intensity data in comparable, standardized terms.

The technique of determining loss percentages by spray tests and applying these to appraisal of loss over a broad area is illustrated in the investigations on potato late blight by P. A. MURPHY (1921), who showed that on Prince Edward Island, late blight caused a loss of more than five million dollars in field and market, the value of the crop being determined with due allowance for freight rates.

Throughout this discussion the problem has been to determine the amounts of loss caused by diseases when there is some reason to believe that important losses do occur. Spray trials may also serve in discovering unsuspected losses. Entomologists have pointed the way to this in tests of the newer insecticides on crops that normally are not sprayed or dusted. PEPPER (1947) has reported that alfalfa yields have been increased 50% or more by a single application of an insecticide. This suggests the value of exploratory fungicide trials on other forage crops and cereals where there is at least a possibility that serious, unsuspected losses from leaf and stem diseases may be revealed.

Effects Of Fungicides On Crops Other Than In Controlling Disease. -- The particular attention that has been given to measurement of losses from cereal rusts by sulfur dusting experiments quite naturally raised the question whether the sulfur has any direct effect on the cereal plant, such as to affect yields favorably or adversely, in addition to its effect in controlling rust. KIGHTLINGER and WHETZEL (1926) found sulfur injurious to cereal yields only if used in excess, and other workers agree that there is no significant direct effect of sulfur on cereal yields. This point is discussed at length, with citations of pertinent literature by NAUMOV (1939) and CHESTER (1946b). The results of three experimental methods bear this out. GREANEY (1934; et al., 1941) found that yields of rust-susceptible varieties were unaffected by sulfur dusting in the absence of rust. PHIPPS (1938), BUTLER (1940), CALDWELL et al. (1934), and BROADFOOT (1931) all showed that sulfur dusting of rust-resistant wheat varieties did not affect their yields. Finally, GREANEY, BUTLER, and BROADFOOT all applied heavy dosages of sulfur to the soil but could detect no effect on wheat yields. These soil applications were at much heavier rates than the soil would receive from crop dusting operations; GREANEY applied sulfur to the soil at the rate of 750 lbs. per acre and BROADFOOT used up to 1920 lbs. per acre without result. It would seem from these results that the sulfur dusting method for measuring losses from the cereal rusts is a reliable one.

Turning to other crops and other fungicides the story is somewhat different. There is abundant evidence of the direct effects of fungicides on crop yields, apart from disease control. Bordeaux mixture, when applied to certain crops that require more copper than is available, results in marked yield increases even though no disease is being controlled by the spraying. On the other side of the ledger, the yield-depressing effects of sulfur on melon crops and tomatoes growing at high temperatures are well known. In Florida the shift from Bordeaux mixture to Dithane sprays for potato late blight has shown yield increases quite out of proportion to disease control. It is not always clear, in such cases, whether the difference is due to elimination of a yield-depressing effect of the one fungicide or to a yield-stimulating effect of the second. It is

quite possible that some of the newer organic fungicides may have growth-promoting qualities in addition to their value in disease control. Whatever the mechanism, these effects are common, and it is obvious that comparison of yields of sprayed and unsprayed plots will not give a reliable measure of loss if the fungicide used has such direct effects on yield.

Yet this cannot be taken as a blanket indictment of the spraying-dusting method of loss appraisal. There are cases in which it can be demonstrated that the fungicide has no direct yield effect, as in sulfur dusting of the cereals. In other cases the direct effect of the fungicide can be measured and used as a correction factor in loss studies. The experimental verification of this point is a simple one; it can and should be a part of all spraying or dusting experiments to measure disease loss; it consists merely in supplementing the ordinary fungicide trial in the presence of disease with a trial in the absence of disease, comparing yields of sprayed plots with those of disease-free unsprayed ones. The latter can be secured by using a disease-resistant crop variety or conducting the tests in a season or under experimental conditions in which there is no natural occurrence of disease on the unsprayed check plots.

Use Of A Graded Series Of Spray Concentrations. -- Comparing yields of healthy sprayed versus heavily diseased unsprayed plots gives a measure of maximum loss but no indication of the increment of loss per unit increment of disease. This last is desirable, because it is unsafe to interpolate values for intermediate degrees of disease, given only two, respectively low and high, points, since with some diseases there is not a linear relation between units of disease intensity and units of loss.

The spraying or dusting method allows the production of a series of times and degrees of disease intensity, of any desired number of stages, by varying the rate, time, frequency, and concentration of fungicide application. The value of this is brought out admirably in YARWOOD'S (1945) study of copper sulfate as an eradicant spray for powdery mildews.

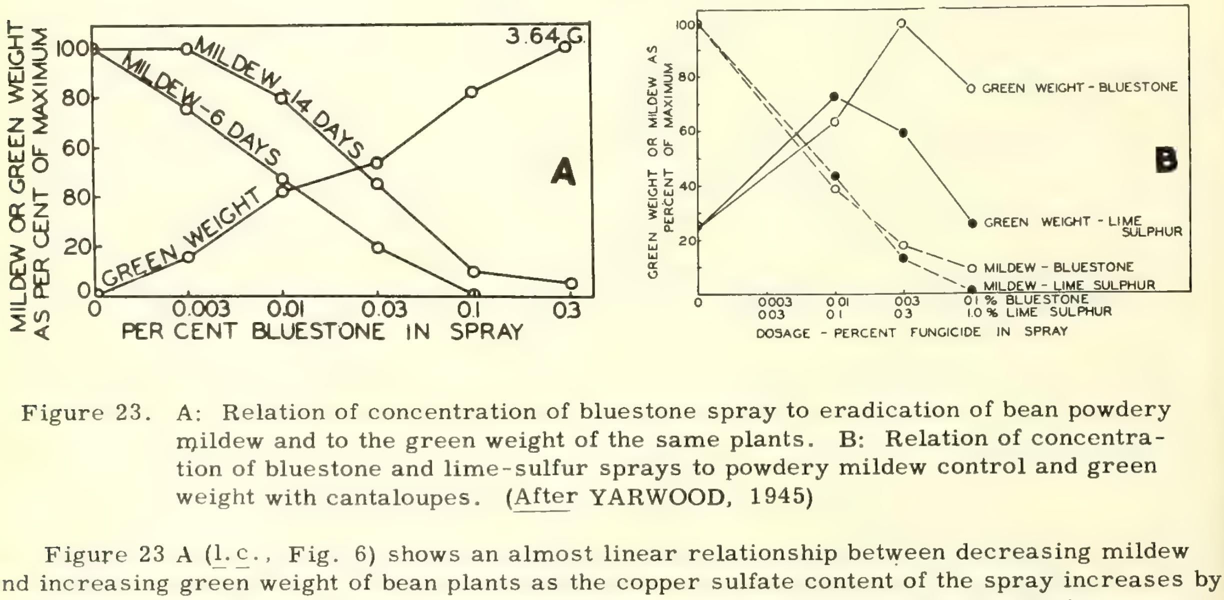


Figure 23. A: Relation of concentration of bluestone spray to eradication of bean powdery mildew and to the green weight of the same plants. B: Relation of concentration of bluestone and lime-sulfur sprays to powdery mildew control and green weight with cantaloupes. (After YARWOOD, 1945)

Figure 23 A (l. c., Fig. 6) shows an almost linear relationship between decreasing mildew and increasing green weight of bean plants as the copper sulfate content of the spray increases by logarithmic steps. Here, if we knew only the values for disease and yield for the highest spray concentration and the unsprayed controls we could interpolate intermediate points without too great inaccuracy. But that this is not always true is brought out for cantaloupes in Fig. 23 B (l. c., Fig. 7). If this experiment had been conducted using only the 0.3% lime sulfur spray, the loss caused by the mildew would have been seriously underestimated, and if the 1.0% lime sulfur spray alone had been used one would conclude that mildew causes no loss, since with this spray concentration the advantage of disease control was almost exactly counterbalanced by the disadvantage of spray injury. Copper sulfate spray at 0.03% concentration alone would have given a fairly accurate measure of loss from the disease, but at 0.1% concentration alone the loss would have been set far too low, since the injurious effect of the strong copper sulfate offset the advantage from disease control to a considerable extent.

Soil Disinfestation Tests. -- The same principles apply to soil disinfestation as to spraying and dusting of crops as a means of loss appraisal. Few soil treatment studies have been made with this objective, but there have been many aimed at control of plant parasitic nematodes and, in a few cases, fungi, the data from which can be used in loss determinations wherever both disease intensities and yields are reported. An example is seen in the work of G. M. ARMSTRONG

(1946) who treated soil with five dosage rates of the disinfestant "D-D", thereby decreasing the root knot index on tomatoes from 3.23 to 0.93 accompanied by a yield increase from 45.4 to 60.7 lbs. of tomatoes per six plots.

As with the spraying and dusting tests there is always the possibility, in this type of experiment, that the disinfestants may have direct or indirect effects on yield apart from controlling the pest concerned. Soil disinfestation radically changes the composition of the soil microbios, both quantitatively and qualitatively altering the populations of harmful and beneficial microorganisms. Cases are known in which soil disinfestation has substantially increased yields without destroying known plant pests, and there are other cases in which the treatments decrease yields through toxicity to plants or destruction of beneficial microorganisms.

The elimination of this source of error is similar to that in the case of spraying or dusting; namely, to determine the effect of the soil treatment on healthy crops and interpret or correct the loss measurements accordingly. Little is known of the extent of damage from many kinds of root diseases, some of which may be causing unexpectedly high losses. It appears that more extensive use of the soil disinfestation method would be a very promising approach to this problem.

THE EFFECT OF ARTIFICIAL MUTILATION ON YIELD; RELATION OF THIS TO DISEASES: -- The effects of removing or injuring leaves of plants hold interest for investigators in many fields. Plant pathologists who would like to know the effects of leaf destruction by rusts and leaf spot diseases see in this a convenient and exact method of studying the losses produced by these diseases, and we find that leaf mutilation experiments have shed considerable light on these losses, especially for the leaf rusts of cereals. Entomologists, too, who are concerned with the damage from leaf chewing insects have found artificial defoliation experiments helpful in appraising this damage.

Agronomists and animal husbandmen are concerned with the effect of loss of leaves on pastures, in an attempt to determine the practical compromise in grazing practice that will give the greatest yield of fodder with the least injury to the plant, especially in the case of cereal pastures where the same crops are used both for grazing and for grain production. Horticulturists are interested in the relationship between leaf surface and number, size, and quality of fruits and nuts, and have conducted important studies on the optimal leaf-fruit ratios, to determine the fruit-thinning practices that will give the greatest financial return.

Plant physiologists also find need for artificial defoliation experiments in their basic studies of the effects of photosynthesis on the chemical composition and development of plants. Ecologists and physiologists both are interested in knowing the harmful or possible beneficial results of loss of leaves from plants which have developed abundant foliage during a cool, moist season, and then are exposed to hot, dry, windy weather in which transpiration is high and the loss of water from plant and soil varies directly with leaf expanse. Plant breeders find it an advantage to learn the laws that govern the relationship between leaf area and yield so that in their plant selection practice they may select the most efficient plants and will know how much reliance to put on leaf area as a criterion of selection.

For the most empirical reasons of all, commercial interests have a stake in the understanding of defoliation and mutilation of plants, the outstanding examples being in connection with hail insurance and chemical defoliation. Excellent experiments by DUNGAN, ELDREDGE, KLAGES, HAWTHORN, KALTON, and KIESSELBACH and LYNESS, using injuries resembling the effects of hail on corn, small grains, onions, soybeans, and flax, have laid the scientific groundwork for determining equitable amounts of indemnity for insured hail damage.

Much less scientific in its approach and basis is the commercial exploitation of the chemical defoliation of plants. The advocates of chemical defoliation enumerate in glowing terms the many advantages that result from removing the "useless, detrimental" leaves of plants as the crop approaches maturity, ranging from facilitating mechanical harvesting to the heightened morale of cotton pickers who are not plagued by mosquitos in the leafless fields and can spend their time picking instead of scratching. These accounts maintain that late season defoliation results in no reduction of yielding ability of the plants, which is not true, although it is probably true that in many cases the advantages of chemical defoliation outweigh its yield-depressing effect, and more than compensate for reduced yield by better quality of the crop, easier harvesting, and other economic advantages.

The studies and interests run the gamut from basic science through applied science to technology. They are found in a wide diversity of publications from academic journals to trade literature and in numerous fields, but all have in common an interest in the relationship between reduced leaf surface and yields. All are embraced in this discussion, for it is frequently the case that the student of loss appraisal will find data, principles, and conclusions which, though derived for an entirely different purpose, nevertheless bear directly on the problem at hand, -- the extent

to which loss of leaves, whether due to disease or other agencies, decreases yields.

Some of the questions involved are these. Are the effects of artificial mutilation comparable to those of disease, so that we may place reliance on such defoliation as a measure of disease loss? To what extent is loss of leaves harmful, considering crop, time and degree of defoliation, environment, and cultural practices? Is defoliation ever harmless or beneficial? How can we account for differences in the effects of defoliation at different growth stages of the crop? How is partial defoliation related to the physiological efficiency of the leaves? What effect does it have on the growth of perennials in the present and future years? An attempt will be made to throw light on these questions, following an account of the methods of experimental mutilation and of measuring leaf areas.

Methods Of Artificial Mutilation. -- The manner of reducing leaf surface has been varied in different investigations. As a general principle, the best method is the one that most closely imitates the type of natural injury under study, but other factors, such as convenience or economy, may influence the methods. Simplest is to remove entire leaves, all that are on a plant or only some of them. This imitates the effects of defoliation diseases and insects, such as grasshoppers, which partially or completely strip the leaves from plants. In China, farmers jerk off sorghum leaves for use as fodder and fuel, and the same method was used by LI and LIU (1935) in studying the effects of this practice on yield.

Next in simplicity, particularly with cereals and grasses, is to clip off distal segments of the leaves, removing 1/4, 1/2, or some other fraction of the leaf. This resembles the effects of leaf injuries caused by drought and by numerous types of disease, in which the leaf dies back from the tip. A variant of this method is to clip grass pasture with a lawn mower, adjusting the cutter bar at some given distance above the ground. This is probably as close an imitation of the effects of pasturing as can be carried out conveniently.

SHCHEGLOVA and CHERNISHEVA (1933) in Russia used the procedure of punching out small areas of tissue leaving round holes in the leaves. With this method it is somewhat inconvenient to determine the percentage of leaf tissue removed, but there would be an advantage in using this practice in imitating injury from those pests which produce circular holes in leaves, such as the shot-hole leaf diseases of stone fruits or the work of leaf-cutting bees and some of the leaf beetles.

In an effort to imitate natural injuries it is not enough merely to simulate the appearance of the injury; the time, duration, and recurrence of the injury must be considered. Some injuries are sudden, others protracted through the season with constant, increasing, or diminishing intensity, and still others come as successive waves of injury. An attempt to imitate this timing is necessary. Instead of cutting cereal leaves transversely, in loss studies, some workers have removed longitudinal leaf sections. This perpetuates the injury, since cereal leaves grow from the base and with longitudinal cutting the fraction of a leaf removed will remain constant with later growth of the leaf remnant. Contrary to criticism by LUBISHCHEV (1940), longitudinal leaf excision does parallel some forms of natural injury, such as stripe disease. DUNGAN'S (1929) method of removing 4-inch sections of corn leaves on alternating sides of the midrib appears to have no counterpart in nature.

Somewhat more complicated and ingenious forms of mutilation, in addition to simple removal of leaves or leaf segments, have been used in efforts to imitate the injury from hail. This is well illustrated in the experiments of DUNGAN (1928, 1929, 1930, 1932) and KIESSELBACH and LYNESS (1945) with corn, KLAGES (1933) with flax, and KALTON and ELDREDGE (1947) with soybeans. The types of injury included breaking the midribs of leaves, splitting them or shredding them with a rasp without removing tissue, cutting off young plants, pounding ears and stalks or bruising with a lath and board, and flailing plants with specified numbers of lashes with a specially devised wire flail of the "cat-o'-nine-tails" type.

Horticulturists interested in leaf-fruit relationships in apples, pears, peaches, grapes, and nuts have made use of HALLER and MAGNESS' technique of removing from a twig a ring of bark and phloem tissues or girdling the twig with wire in order to confine the products of photosynthesis from the leaves distal to the ringing operation, making them available only to the fruits or nuts on the same twig portion. In this way a certain number of fruits receive foodstuffs only from a given number of leaves, and this leaf-fruit ratio has either been left as in nature, increased by removing some of the fruits, or decreased by removing some of the leaves.

The interest of entomologists in losses from insect defoliation is brought out in such studies as those of MINOTT and GUILD (1925), GRAHAM (1931), SUMMERS and BURGESS (1933), BAKER (1941), and WALLACE (1945). This work suggests the possibility that plant pathologists might apply the entomological findings to appraisal of loss caused by diseases with effects comparable to those of leaf-feeding insects, or even deliberately make use of insect injury as a form of mutilation in disease loss investigations. The entomologists have not only worked with natural insect attacks but have also simulated them, with an attempt to duplicate the manner of action of the in-

sects, as in the work of WHITE (1946), who attempted to defoliate wheat in the same fashion as grasshoppers do.

Chemical defoliation is more comparable to loss of leaves from frost than to most other natural hazards, because of its suddenness and completeness. Calcium cyanamid is commonly used for this purpose, at the rate of 30 to 40 lbs. per acre, applied when the plants are moist, by airplane or any ordinary ground dusting equipment. The leaves begin dropping off in 24 to 48 hours and the dusted plants have lost all leaves 5 to 15 days after the application.

In a few cases other parts of the plant than the leaves have been mutilated or removed in loss studies, as with stem injuries and the removal of terminal buds in connection with injuries in imitation of hail damage. H. M. BROWN (1944) simulated the effect of loose smut by removing wheat heads at heading time, which produced approximately the same loss as an equal percentage of smutty heads.

Methods Of Measuring Leaf And Fruit Areas And Fruit Volumes. -- Accurate study of the relationships between leaf area, defoliation, and yield often requires some method of measuring leaf area. Numerous methods have been used for this, and the choice of method is dictated by leaf shape and its constancy, convenience, rapidity, and degree of accuracy required.

Most elementary is to measure the leaf area with a planimeter. This is inconvenient, however, because of the thickness, softness, and wilting of detached leaves. This disadvantage can be obviated by first reproducing the leaf outline on paper, using blueprints (LOTT and LEMERT, 1932; GUSTAFSON and STOLDT, 1936) or charting the outlines on paper. STANILAND (1946) has described a drawing apparatus for projecting on paper scale replicas of leaves *in situ*.

To save the time required by planimeter measurements, some workers have followed the practice of outlining leaves on paper of uniform thickness and cutting out and weighing these. A conversion value is obtained by weighing paper of a known area, and the weights can then be fairly accurately converted into units of area by a simple calculation.

Still more rapid though somewhat less accurate, is to estimate the areas, using estimation aids. One way is to prepare a set of standards of leaves of different sizes, which may be leaf tracings or blueprints, measure these with a planimeter, and estimate the areas of leaves by comparing them with these standards (*e.g.*, BALD, 1943*a*). Another method is to prepare a set of celluloid patterns, shaped like leaves and of a graded series of sizes, measure these accurately, cover a leaf with the one most closely corresponding to its size, and estimate its overrun (SCHUSTER, 1933). A variant of this is to cover the leaf with a glass grid, ruled in squares of standard size, estimating the area from the number of squares occupied by the leaf (VYVYAN and EVANS, 1932).

Other workers prefer to use methods based on measurement of one or both diameters of leaves. With leaves of fairly constant shape, measurement of one diameter may suffice. CARUTHERS (1929) found this true of leaves of *Ribes* and prepared a scale, resembling a logarithmic ruler, on which area can be read off directly, knowing leaf width. He found the method accurate within 5% error. With tomato leaves, A. M. PORTER (1932) found a highly significant curvilinear relationship between leaf area and length ($r = .968 \pm .0018$), so that leaf area could be calculated from length using an equation that fitted the curve, or more readily by reading area directly from the curve.

Multiplying the product of leaf length and width by a constant, DARROW (1930) with strawberry, MARSHALL (1933) with raspberry, and DAVIS (1940) with bean leaves all found this a satisfactory method of obtaining leaf areas. BATEN and MUNCIE (1943; BATEN, 1942) carried this one step farther by preparing nomograms from which areas of bean and sugar beet leaves can be read directly, knowing their length and width. MARSHALL (*l. c.*) has described a very ingenious mechanical device for this purpose, consisting of two syringes with plungers attached to stiff, indicator wires, their liquid contents being forced into a vertical tube with a calibration scale for leaf area. A leaf to be measured is placed on a platform, the two plungers, at right angles, are pushed in until the wires touch the end and side margins of the leaf, and the area is read directly from the level of liquid forced into the vertical tube. The equipment was calibrated by using planimeter measurements, and had accuracy within 1% for a considerable number of leaves.

If leaf area is well correlated with some other easily measured portion of a plant, it may be most convenient to make use of this correlation. SCHUSTER (1933) found such a useful correlation between twig length and leaf area in working with filbert.

The most highly developed methods for measuring leaf area make use of photometers or photoelectric devices. The "phyllometer" of BOLAS and MELVILLE (1933) is a relatively simple photometric device based on the principle that the larger the leaf the less light will pass to a photometer in which a dial adjuster is turned to the limit of visibility of a black cross against a white background. The dial readings are calibrated with leaves of known size. Leaf measuring devices based on degree of activation of a photoelectric cell have been described, improved, and used by

GERDEL and SALTER (1928), BERGMAN (1933), FREAR (1935), WITHROW (1935), MITCHELL, (1936), KRAMER (1937), HIBBARD et al. (1938), and MILTHORPE (1942). The principle is that the smaller the leaf, the greater the amount of light transmitted and the resultant electric current, which is converted into leaf area after calibration with measured leaves.

BATEN and MARSHALL (1943) have published equations for determining the surface areas of such fruits as apple, pear, and plum, and the volume of fruits may readily be obtained by water displacement.

Interpretation Of The Leaf Area-Yield Ratio. -- The quantitative and qualitative effects on yield of leaf area and its reduction are complex, varying with crop and variety, amount, time, and manner of defoliation, and environment in which the crop is growing. As we might expect, this results in apparent inconsistencies or contradictions when one case is compared with another, yet there are certain principles that apply generally. The subject of defoliation in relation to crop loss has been discussed at some length by CHESTER (1945a) and EIDELMAN (1933 a, b).

It is generally true that any defoliation, at any stage in the development of the crop, with the possible exception of the last few days before crop maturity, produces some reduction in yield. ROEBUCK and BROWN (1923) and R. M. WHITE (1946) have found this true for wheat, HUFFINE (1947) for sorghum, GIBSON et al. (1943) for soybeans, CROWTHER (1941) for cotton, and others for a number of other crops.

Defoliation sometimes has little effect on one type of organ or even stimulates its development, but at the expense of other organs and of the growth of the plant as a whole. In the case of soybeans (l. c.) moderate defoliation increases the yield of leaves while seed production is reduced, and with onions, defoliation reduces bulb formation without having much effect on seed production (YARWOOD, 1943).

With different degrees of defoliation at any one time, some workers consider that the percent reduction in growth or yield is approximately equal to the percent of defoliation (SUMMERS and BURGESS, 1933, for hardwoods; DUNGAN, 1929, for corn), but in the majority of cases the cause and effect are not proportionate. Ordinarily the percent of loss seen in comparing plants having 100% of their foliage with plants having 90% foliage is less than the percent of loss seen in comparing 90% foliated with 80% foliated plants and, continuing in this fashion, each additional 10% increment in defoliation results in a greater percent of loss than preceding ones. This principle has been observed and expressed in different ways in defoliation experiments with tomato (GUSTAFSON and STOLDT, 1936; A. M. PORTER, 1932), corn (DUNGAN, 1930), apple and pear (MAGNESS et al., 1928, 1929, 1931), peach (WEINBERGER and CULLINAN, 1931, 1932), grape (WINKLER, 1930), and filbert (SCHUSTER, 1933).

The relation between leaf area and both quantity and quality of fruit is brought out in WEINBERGER'S data on peach thinning and defoliation, presented here in Table 5, which illustrates the increasing importance and efficiency of the remaining leaves as the degree of defoliation increases.

Table 5. The relation between Late Crawford peach leaf area and fruit size and quality. (After WEINBERGER, 1931).

Leaves per fruit	Leaf area per fruit[a]	Size of fruit[b]	Efficiency of leaves[c]	Dry weight of fruit[d]	Total sugars (%)
75	538	133.7	2.5	17.16	10.84
50	538	124.9	3.5	17.38	11.21
40	286	128.3	4.5	17.38	10.74
30	215	115.8	5.4	16.51	10.38
20	143	117.2	8.2	15.43	9.69
10	72	78.5	10.9	13.49	8.11
5	36	42.5	11.8	10.62	4.63

[a]In sq. inches. [b]In c.c. [c]As c.c. of fruit per 10 sq. inches of leaf area. [d]As % of fresh weight.

The explanation why the first leaves lost are more dispensable, causing less damage to the plant than further equal increments of defoliation, is expressed in terms of the efficiency of the leaves. When a plant has its full complement of leaves, these are functioning at a relatively low

efficiency, but as more leaves are lost, those remaining function more and more efficiently and their loss is more detrimental to the plant than that of the first, inefficient leaves that are lost (Table 5). When a plant has other green, photosynthetic tissues than leaves (leaf sheaths, glumes and awns, green stems) the loss of leaves is less serious than in plants lacking these partly compensating tissues (cf. DUNGAN, 1932). EIDELMAN (1933b) has shown that wheat leaves normally are not used at full efficiency, and that removing some of them increases the photosynthetic activity of the remaining ones, although not enough to compensate fully for the cutting.

Defoliation is regularly associated with a decrease in quality of the crop, the cause and effect showing the same disproportionate relationship with increasing degrees of defoliation as was the case with gross yield. Table 5 illustrates this in showing the decrease in sugar, a prime quality factor, with decreasing leaf area per peach. The same thing has been observed in apples and grapes. Apples with a low ratio of leaf to fruit have been found to be insipid, with little aroma, and almost inedible (MAGNESS, 1928).

As the degree of defoliation increases, soybeans contain less oil and have shrivelled seed (KALTON and ELDREDGE, 1947), corn becomes floury and chaffy (DUNGAN, 1928) and has a reduced content of sugar in the stalks (SAYRE et al., 1931), onions show a higher percentage of boilers and culls as compared with the jumbo and medium grades (HAWTHORN, 1943, 1946), and wheat contains less protein and sugars, has a reduced bushel weight, and produces flour of poorer baking quality.

There are also serious secondary effects of defoliation, as in the case of tomatoes where loss of leaves exposes the fruits to sunburn. With a number of crops, defoliation retards the date of maturity with numerous undesirable effects, including loss of the high prices paid for early-harvested crops and increased danger from late-season weather and pests. Also, of a secondary nature, but important to the yield and quality of the crop, is the fact that defoliation leads to a reduction in root development and, in turn, a reduction in mineral and water uptake, which aggravates the direct loss.

Thus far we have been considering degree of defoliation, with time of defoliation a constant or neutral factor. Reversing this procedure brings out important principles governing the effects of defoliation at different growth stages of the plant.

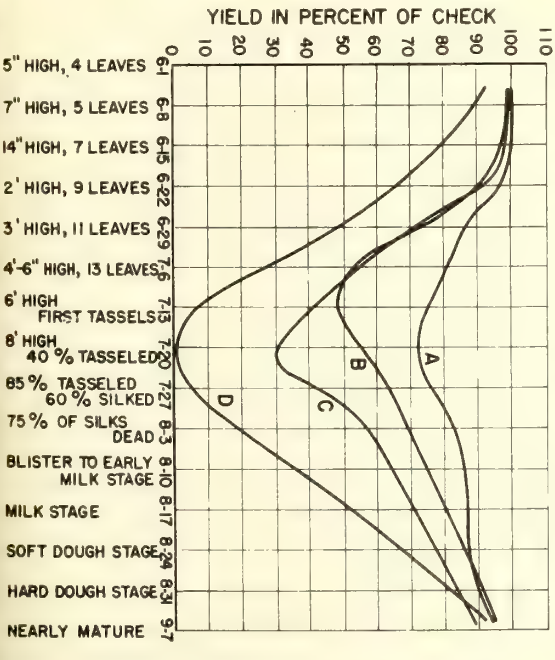


Figure 24. The effect on corn yields of 1/2 (A), 2/3 (C), and total (D) defoliation at different stages in development of the corn plant. Curve B shows the effect of shredding the corn leaves. (After ELDREDGE, 1935).

Consider a uniform planting subdivided into groups of plots, one group being completely defoliated early in the development of the crop and then undisturbed for the remainder of the season, a second group defoliated once at a somewhat later growth stage, and other groups defoliated at successively later dates, extending to maturity of the crop. If now the yields of these plots are measured we regularly find, with such various crops as corn, barley, oats, sorghums, onions, flax, and soybeans, that the loss in yield is greatest when the plants are defoliated in midseason and progressively less with earlier or later defoliation. This is well illustrated for corn in Figure 24.

As the figure shows, comparatively little loss results from complete defoliation when the corn is only 5 inches high, more and more loss results as defoliation is progressively later, until the time at which the corn is 8 feet tall and 40% tasselled, when complete defoliation causes total loss. With defoliation at progressively greater intervals after this growth stage, the yield reduction is less and less, until the effect on yield is minor if the crop is defoliated when it is nearly mature.

The figure also shows a comparable result if defoliation is partial, not total, the effect on yield being less in degree but similar in character as smaller percentages of the leaves are removed. In all cases any indicated amount of defoliation is most injurious at midseason and least very early or very late in the development of the crop.

Results similar to those of ELDREDGE with corn have been reported by HUME and FRANZKE (1929) and KIESSELBACH and LYNESS (1945). The latter workers also observed the "midseason effect" on yields of corn stover and fodder and have published an excellent photograph, reproduced here as Figure 25, showing graphically the relation between time of defoliation and corn ear development.

Figure 25. Effect of complete defoliation, at different growth stages, on typical corn ear development. Left to right, growth stage at time of development: check; plants 2 feet tall; 3 feet tall; 4 feet tall; initial tasseling; fully tasseled; 10 days after silking; early milk; and late milk stage. Acre yields, left to right respectively were: 52.7; 50.1; 43.3; 20.3; 0.0; 0.9; 12.5; 15.4; and 31.6 bushels per acre. (After KIESSELBACH and LYNESS, 1945.)

The time or growth stage at which defoliation is injurious is: for oats and barley, when in the grass stage before the growing point has emerged from the crown (ELDREDGE, 1937); for sorghums, 60 days after planting (HUFFINE, 1947); for flax, in the bud stage (KLAGES, 1933); for soybeans, when the beans are beginning to develop in the pod (KALTON and ELDREDGE, 1947); and for onions, when bulbing begins (HAWTHORN, 1943, 1946).

Some workers have reported merely that the effects of defoliation are greater the younger the plants are when defoliated. This contradiction is only apparent, because in each of these cases the defoliation was begun at or after the time of the midseason effect, without consideration of its effect earlier in the life of the plant. In an early study of DUNGAN'S (1928), for example, corn defoliation began after the plants had tasselled, and as a result he observed only the right-hand half of the curve shown in Figure 24. He observed the entire curve of effect in later work (1931). The same thing is seen in ELDREDGE'S (1937) work with wheat, where defoliation was not begun until the plants were at least six months old and well into the jointing stage, and in the sorghum defoliation experiments of LI and LIU (1935), begun when the crop was in the dough stage.

The most probable explanation of the "midseason effect" is that at this critical stage in development the foliage has not yet served its photosynthetic function, yet it is too late for the plant to develop a new set of leaves to compensate for those lost. With defoliation progressively earlier than this, the plant has more time to replace the lost foliage, which then is able to function fairly well, while with defoliation progressively later than the critical period, the leaves have served their purpose to an increasing extent, and to the same extent are dispensable.

Wheat provides an important source of fall and spring forage, and there is much interest in the amount of grazing that it can yield without serious injury to the grain yield. Experiments in the Southwest show that a considerable portion of the leaves of young wheat plants may be grazed off without much effect on grain production. This loss of leaves is quite early in the morphological development of the wheat plant, and therefore has little effect on grain yield. Winter wheat

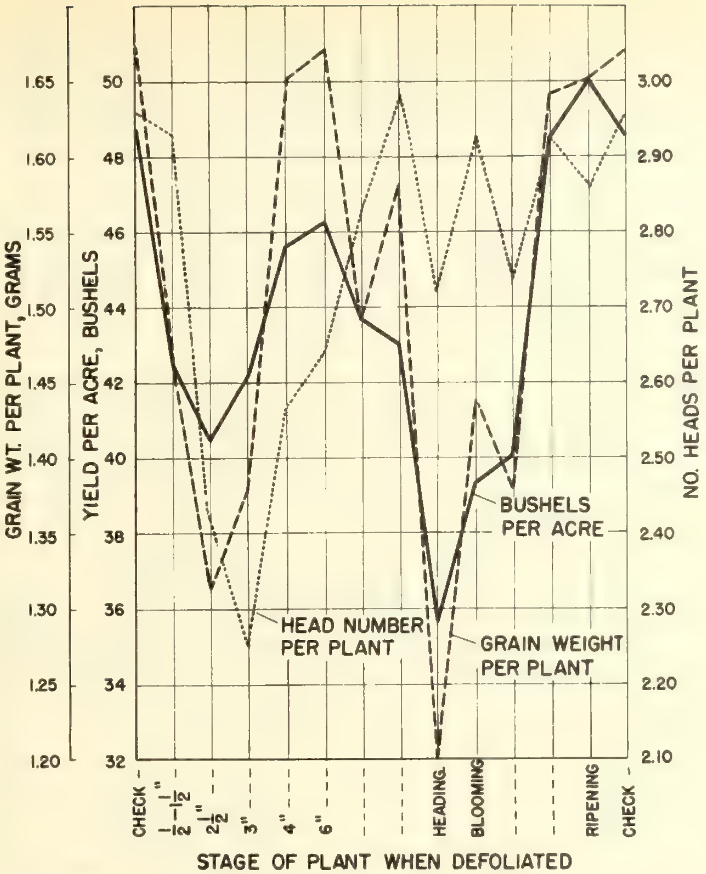


Figure 26. Effect on wheat yields of defoliation at different stages in development of the wheat plant, illustrating a double valley in the yield curve due to anatomical and nutritional effects of defoliation. (After WHITE, 1946.)

plants in the spring may be several months old, to be sure, but the winter dormant period has protracted the life of the plant in a juvenile condition. In this case, also, the leaves removed by grazing are but a small fraction of all leaves on the plant. When wheat pasturing is prolonged in the spring the result is serious or even total loss of grain yield.

Apparently anomalous results have been obtained in R. M. WHITE'S (1946) defoliation experiments with wheat as shown in Figure 26. Here yield, whether expressed as grain per head or bushels per acre, was most depressed by defoliation at the heading stage, but there is a second valley in the yield curve indicating serious yield reduction resulting from defoliation when the plants are 2-1/2 inches high, with less effect of defoliation between these two growth stages. How can this double valley be explained?

It is quite likely that the maximum loss in yield due to defoliation at the heading stage, as in other crops, is due principally to the inability of the plants to fill the grains, since the morphological framework of the plant and its reproductive parts has been fully differentiated by the time the heading stage is reached. The loss in yield associated with defoliation at the 2 1/2-inch stage, on the other hand, appears to result from a failure of the injured plant to differentiate its organs and form the framework of normal plant structure, and this is borne out by the curve showing the number of heads per plant, which has but one deep valley, associated with defoliation at the 2 1/2- to 3-inch stage.

A slight tendency toward a double valley is also seen with defoliation of soybeans in the data of KALTON and ELDREDGE (1947), where yield is somewhat more depressed by defoliation when the plants are 4 to 6 inches tall than when they are 7 to 9 inches tall, with the remainder of the defoliation-yield curve showing only the typical "midseason effect".

Turning to the effect of environment on the leaf area-yield relationship, a number of investigators have shown that loss of leaves is least detrimental under drought conditions, where a moderate degree of defoliation may even increase corn yields (ELDGREDE, 1935). LUDWIG (1927) has reported that late defoliation of cotton results in death of twigs or even whole plants if the soil is moist, but not if it is dry. In South Russia, MOLOTKOVSKY (1945) has gone so far as to recommend mowing potato vines in midsummer, and has presented rather variable data which suggest that yields are frequently increased by this method. This is evidently an atypical case in which the growing season is regularly interrupted by heat and drought, and in which the defoliation has the main purpose of retarding crop maturity until a time of more favorable weather.

LUBIMENKO (1933) has given special attention to this aspect of defoliation. He defines the "coefficient of damage" as "that factor by which it is necessary to multiply the degree of damage to the vegetative organs in order to obtain the actual effect of the damage, i.e., the amount of loss in quantity and quality of the yield." EIDELMAN (1933a), in summarizing the extensive Russian work on artificial defoliation, has computed the coefficient of damage for 100% defoliation of spring wheat as .24-.28 at Kiev and .48-.69 at Leningrad, i.e., the yield reduction for the same degree of injury was much greater at Leningrad. This is interpreted as meaning that under the environmental conditions at Kiev the wheat had a greater capacity for compensating for

deficient leaf tissue through increased activity of the remaining tissues.

Under dry conditions leaves may be more efficient, and it has been shown that in dry soils a smaller leaf area is required to produce a bushel of sorghum (SWANSON, 1941) or to produce peaches of a given size and quality (I. D. JONES, 1931). Total yields are greater under moister conditions in these cases, because there is greater leaf area, even though it is less efficient. As regards soil fertility, we have the statement of EIDELMAN and BANKUL (1933) that fertilizers act on defoliated plants in much the same fashion as on normal ones.

The manner of defoliation is a factor in the effect on yield. This is well seen in experiments using various types of injuries in imitation of hail damage. For example, cutting off the outer half of a corn leaf, removing a longitudinal half, removing alternate entire leaves, and removing 4-inch sections on left and right sides of the leaf alternately, all eliminate essentially 50% of the leaf tissue, yet the effects in depressing yield are quite different in the four cases, the first method producing the greatest loss (DUNGAN, 1930).

Different crops and different varieties of the same crop vary in their response to defoliation. For example, EIDELMAN and BANKUL (1933) have reported that the yield of barley is less affected by defoliation than that of wheat, GIBSON et al. (1943) found that defoliation reduced yields of the Tokyo soybean less than those of the Biloxi variety, and WEINBERGER (1931) has shown that it takes more leaf area to produce a given fruit volume in the Crawford peach than in the Elberta.

With perennials the effects of loss of foliage are seen both during the year of defoliation and in the following years. This subject has been studied especially by entomologists with interest in the work of such leaf feeding insects as the gipsy moth and cankerworms, e.g., GRAHAM (1931), BAKER (1941), and WALLACE (1945). A single defoliation may kill evergreen conifers, while hardwoods suffer decreased radial and twig growth and may be killed in three to four years by the action of the complete defoliation, directly, or by secondary pests favored in their work by weakness in the trees. Different species and individual trees of a single species vary in their response to defoliation, depending on their genotype and environment.

The work on ringing fruit and nut trees, referred to above, shows that the normal complement of leaves is usually inadequate to give the best economic returns from the trees. Fruit thinning is now a recognized desirable practice in order to increase the leaf-fruit ratio and thereby secure larger fruits of better quality. Any fruit thinning reduces yields but moderate thinning, to a point where each apple, pear, or peach fruit, for example, is supplied with 30 to 40 leaves, increases the value of the crop, the higher quality more than offsetting the slight reduction in crop volume. Tomatoes are thinned for similar reasons. With tree fruits, thinning also has the advantage of making available more needed foodstuffs as reserve food in the wood for the following year.

The case of late-season chemical defoliation, which is becoming a standard practice with cotton and some other crops, also deserves special mention. Enthusiasts of chemical defoliation indicate that the leaves of crops such as cotton and soybeans are quite useless during the last weeks before maturity. M. V. BAILEY (1947) calls cotton "an excellent example of a plant which retains its foliage long after it is of any value in growing the crop or increasing the yield." Contrary to this notion, LUDWIG (1927) for cotton and KALTON and ELDREDGE (1947) for soybeans have shown that defoliation at any stage decreases yields.

Nevertheless, chemical defoliation has, or is claimed to have, many advantages, most important of which are the facilitating of mechanical harvesting operations and forestalling of unfavorable late-season weather. According to the accounts of M. V. BAILEY (1945, 1947) and GULL and ADAMS (1945, 1946), defoliated cotton produces lint that is relatively free of chlorophyll and mold stain, suffers less from boll rots, may be picked with greater comfort and earlier in the morning, opens its bolls sooner, which dries the lint and improves the lint grade, contains less foreign matter in mechanically harvested lint, facilitates hand picking by making it easier to see the bolls, which doubles the picking rate, starves the late-season overwintering brood of boll weevils, enables growers to harvest in time to comply with the Texas law that requires all cotton plants to be destroyed by September 1 for pink bollworm control, and permits a degree of irrigation that would otherwise be inexpedient because of excess foliage produced. With soybeans the earlier maturity due to chemical defoliation makes it possible to fit this crop into a desirable rotation plan with wheat, and decreases storm damage to the beans. With tomato it is said to accelerate maturity, facilitate harvesting, and increase yields of ripe and uncracked fruits; from what is known of shading in relation to vitamin formation, defoliation would probably also increase the content of ascorbic acid in tomato fruits. It is used with nursery stock to induce dormancy, aiding fall digging of stock. It is recommended for ramie to aid harvesting and facilitate decortication. With potato the entire plant is killed by chemicals to aid early harvesting when the price is high and to prevent infection of the tubers by the late blight fungus.

Although these claimed advantages of chemical defoliation have not always been subject to critical testing, there seems little doubt that in many cases they may outweigh the disadvantages, including some loss in volume of yield, especially if defoliation is delayed until the plants are nearly mature. The effects of chemical defoliation are so complex and far reaching that it may be that the test of time and practical experience is the best arbiter of the value of this practice.

Since much of the work on artificial defoliation has been done with other objectives than disease loss appraisal, the application of the results to an understanding of disease losses is somewhat theoretical. There appears to be general agreement, however, that the losses caused by leaf clipping are similar to, but somewhat less severe than, those caused by an equal loss of foliage from leaf rust diseases (Anon. 1933, 1934, 1936; RUSAKOV 1929b). CHESTER'S (1946b, Fig. 2) presentation of losses from wheat leaf rust shows that the results of leaf clipping experiments are in good agreement with those revealed by infection and sulfur dusting tests. There appears to be no contrary view that artificial defoliation is not comparable to the effects of disease if we except LUBISHCHEV'S (1940) general denunciation of the method as used by Russian workers, which is based on no original evidence and reveals a lack of understanding of the physiological and pathological principles involved.

If there is any discrepancy between the results of leaf clipping and those of leaf rust, the effects of the disease are somewhat more severe (CALDWELL and COMPTON, 1939; SHEVCHENKO, 1933). This might be expected since leaf disease, besides eliminating leaf tissue, has other harmful effects, such as inducing excessive transpiration and respiration, decreasing the palatability of forage, and, in some cases, the production of toxins which are damaging to the plant or the animal that consumes the plant, or both. The effects of disease are usually progressive, giving the plant less opportunity to recover from the loss of foliage than in mutilation experiments as usually conducted. All this leads us to the conclusion that the results of artificial defoliation experiments give us a conservative measure of the losses caused by disease that destroys an equal amount of tissue. If this is true we are justified in applying some of the principles brought out in artificial defoliation experiments to an interpretation of the effects of plant disease.

Since any degree of artificial defoliation causes some reduction in yield, it follows that any loss of foliage from disease also reduces yields. It also follows that the damaging effect of leaf diseases will be proportionately greater with each succeeding increment of loss of foliage. We may infer that loss of foliage from disease in midseason, at the time when artificial defoliation results in greatest losses, will be most harmful, which leads us to focus most attention on those diseases that defoliate plants which have developed a full complement of leaves but have not yet made extensive use of these leaves in food production and storage. If the "double-valley" phenomenon described on page 313 is significant and common, there is a second danger point in the developmental cycle of plants, when they are in a formative stage, at which time loss of leaves may lower yields seriously by preventing proper formation of the plant structure. This is at an early stage when defoliation diseases such as the Septoria leaf spots of cereals are frequently considered as relatively harmless.

Continuing the parallel, the loss from leaf diseases must include qualitative as well as quantitative yield factors. If the greatest economic return from orchards results when there are 30 leaves per fruit and this must be attained by fruit thinning, it is clear that any defoliation by disease will reduce this ratio, making more radical fruit thinning necessary if fruit quality is to be maintained, and it has been shown that gross yields decrease with degree of thinning. The other forms of qualitative loss from artificial defoliation, discussed above, may be expected to follow defoliation by disease.

If it is objected that the manner of defoliation in mutilation experiments is unnatural, it must be recalled that virtually all of the methods of defoliation that have been used have analogies, in character and degree, among the effects of various diseases, including diseases that kill the distal portions of leaves, others that destroy longitudinal segments of leaves, others that shred leaves, and still others that kill in well-defined leaf spots, simulated by the leaf punching experiments.

Since different crops and different varieties of the same crop suffer to different extents from artificial defoliation we can expect the same principle to apply to defoliation diseases, and this is indeed the case as witnessed by the observed "tolerance" of some crops and varieties to leaf diseases. It has been shown that barley is somewhat more tolerant to artificial defoliation than some other cereals, and the ability of barley to produce a fair yield of grain despite drastic loss of leaf from rust, powdery mildew, bacterial blight, and Septoria leaf spot is a matter of common observation. The post-seasonal effects of artificial defoliation of trees have their exact counterpart in the effects on the succeeding years' development or even death caused by needle-cast diseases and such leaf diseases of angiosperms as cherry leaf spot.

The relative harmlessness of loss of leaf seen in experiments in which leaves are removed under drought conditions or at the end of the growing season, leads us to infer that leaf diseases are also least injurious and possibly even beneficial at such times. It may not be desirable to combat diseases that act in this fashion, but we can hardly expect to use them to induce desired defoliation in view of our lack of control of the development of disease in nature and the highly controllable method of chemical defoliation.

In summary, the method of artificial mutilation to determine losses resulting from defoliation appears to be a sound, reliable, and conservative approach to an understanding of the losses caused by foliage diseases. It challenges some of our traditional concepts of the damage from disease, confirms others, and stimulates the investigation of some of the little known aspects of the economics of plant disease.

COMPARISON AND COMBINATIONS OF METHODS: -- Of the various methods used in appraising loss from diseases each has advantages and limitations. A method which is entirely suitable for one type of disease may not be applicable to another type. Comparison of yields of plants from inoculated or naturally infested seed with those of plants from disease-free seed is an ideal method for exclusively seedborne diseases, but would be quite unsuitable for soilborne or airborne diseases. Like a well-equipped craftsman, the plant pathologist has at his disposal a variety of tools for ascertaining disease loss, calling for judgment in the choice of a tool or method for any given disease problem. The examples given in the preceding sections may serve as a guide to those methods that have been found most useful in determining loss from various types of disease, and in each case the advantages and limitations of the several methods have been pointed out.

Looking through the literature on disease loss appraisal we find numerous cases in which investigators have made good use of combinations of techniques. Those who have been concerned with cereal rusts have carried out parallel experiments involving sulfur dusting of plants, comparisons of disease resistant and susceptible varieties, infection tests, and artificial defoliation, and the results by the several procedures have been in harmony. EZEKIEL and TAUBENHAUS (1934) used three mutally confirmatory methods in appraising the loss from Texas root rot in cotton.

It may be emphasized that such combinations of two or more loss appraisal methods are often desirable. The results obtained by one technique tend to confirm, correct, or qualify those obtained by another. One method may extend the applicability of another, more intensive method. A combination of methods tends to reveal the shortcomings of any one of them, and the reliability of a conclusion that can be verified by each of several experimental or observational processes makes it more defensible for the various uses of accurate information on plant disease losses discussed in Chapter I.

Chapter X

ANALYSIS AND SUMMATION OF DISEASE INTENSITY-LOSS RELATIONSHIPS

STATISTICAL SIGNIFICANCE IN DISEASE LOSS APPRAISAL STUDIES: -- It has been suggested before, and may be emphasized here, that experiments in determining loss from plant diseases are quantitative experiments, requiring the same techniques in experimental design and statistical analysis of the results as are required in other quantitative biological studies where there is more or less uncontrolled variation in repetitions of treatments, materials, and environments. In particular, the statistical methods used with agronomic field work have a parallel in those required for disease loss studies, and the manuals of statistical methods for agricultural experimenters, such as SNEDECOR'S "Statistical Methods Applied to Experiments in Agriculture and Biology" (Ames, Iowa, 1946), are indispensible guides to reliable experimentation in this field.

In loss studies of earlier years, and occasionally in more recent ones, there has been no attempt to determine the statistical significance of results and we have only such general statements as: "Small percentages of wilt infection did not materially affect yields, but where the larger counts of wilted plants occurred the yields were generally lower." This is not very helpful in trying to arrive at an exact picture of loss.

Statements on the significance of losses may also be misleading when statistical significance and economic significance are not distinguished. In a study of the effect of virus diseases on potatoes, for example, the spindle tuber disease did not cause a "significant" reduction of yield unless 32% or more of the plants were affected, nor did leafroll if less than 24% was present. It is quite evident from other work that there is economic significance to lesser amounts of these diseases and that there would undoubtedly have been statistical significance to losses from the lower percents of disease had the tests been more extensive or more uniform.

Many loss studies might be cited in which exemplary use has been made of approved statistical methods. This is particularly true of recent papers from Canada such as that of M. NEWTON, PETURSON, and MEREDITH (1945) on losses from barley leaf rust, and SALLANS' (1948) study of the effect of root rot on wheat yields, as well as the work of BALD (e.g., 1943b) in Australia. Other good examples of the statistical treatment of loss data are mentioned in the following sections.

CORRELATION BETWEEN DISEASE INTENSITY AND YIELDS: -- When extensive data on disease intensity and yields of diseased and healthy crops are available, the relationship between disease and yield may be simply expressed as a coefficient of correlation. This not only brings out the extent to which disease is responsible for yield reductions, but also, by using partial correlations, it is possible to allocate the fractions of total yield reduction due to several injurious factors acting as a complex.

The study of SALLANS (1948) on the interrelations of common root rot and other factors with wheat yields in Saskatchewan is an excellent illustration of this method. His Table 3 gives simple and partial correlations between preseasonal rainfall, June-July rainfall, air temperature, root rot, insect damage, and yield. It was possible to develop a yield formula which accounted for 77.8% of the variance in yield when these factors were considered, with only 22.2% of the yield variance due to error or unaccounted for. The regression of yield on common root rot was -0.583 with a standard error of $\pm$ 0.203 bushels per acre for each increase of one unit in the disease rating, indicating a substantial yield decrease from disease. The variance in yield associated with common root rot was second only to the portion related to June-July rainfall, and greater than the variation associated with preseasonal rainfall, air temperature, or insect damage. The average disease rating for the study was 8.81 units, corresponding to a loss of 5.14 $\pm$ 1.79 bu. per acre or one third of the yield harvested, with 95% fiducial limits of 1.55 and 8.37 bushels per acre. The lowest limit here is not far from the annual estimates of loss from root rot in Manitoba and Saskatchewan, indicating that the estimates of losses from this demonstrably destructive disease have been ultra-conservative. These details are given to bring out the usefulness of such analysis of data in appraising losses.

Correlation studies comparable to this have been made of loss factors in cotton (CROWTHER, 1941) and oats (IMMER and STEVENSON, 1928), and the use of simple correlations between disease and yield is illustrated in the work of IMMER and CHRISTENSEN (1928, 1931) and HAYES (1926) on corn smut, and ROBERTSON *et al.* (1942) on wheat foot rot. The literature also contains data for which correlations could be calculated although this has not been done, as in the case of SALMON and LAUDE'S data on wheat yields, leaf rust, and *Septoria* leaf blotch, and the excellent entomological paper of C. C. HILL *et al.* (1943) relating the number of Hessian fly

puparia per wheat culm to the percent of culms infested, and this to yield reduction. RIHA (1928) has pointed out the economic advantages that would result if correlation coefficients could be established to estimate in advance the yield reduction from important potato diseases.

CORRELATION BETWEEN STANDS AND YIELDS: -- If the principal effect of a disease is to reduce or thin out stands, the loss caused will be a function of the extent to which stands and yields are correlated. If reduction of stand does not seriously reduce yield, because of compensation for missing plants by greater productivity of adjacent ones, the disease may be of little significance. Many of the available data on disease intensity, especially from seed treatment experiments, are reported in terms of stand, not of yield, but if the stand:yield relationship is known, as well as that between disease and stands, it might be possible to determine losses from disease intensity data on the simple basis that if A:B and B:C are known, A:C can be calculated.

The study of the relationship between yields and the density and uniformity of stands serves several useful purposes. Chief of these, from our point of view, is the way in which such study aids in appraising and interpreting the losses caused by those diseases that have as their principal effect the depletion of stands. In evaluating effects of depleted or irregular stands, whether this is due to disease or other causes, it is helpful to have a sound basis for calculating the theoretical yields of perfect stands, and this can be done by making use of the findings of stand-yield studies. In certain types of experiments, plots must be rogued (p. 294), and stand-yield information enables us to estimate the theoretical yields of unrogued plots. To some extent gaps or missing plants in a stand are compensated for by greater productivity of adjacent plants which make use of the soil, water, light, and space vacated by the missing plants, and stand-yield studies give us a measure of this compensation, whether associated with disease or with other hazards. Finally, stand can be determined early in the season, and where this is well correlated with yield, as it is in the case of corn, it becomes an important factor in the early forecasting of yields (Anon., 1947).

Some of the valuable sources of information on stand-yield relationships are found in purely agronomic studies. Although these have not been concerned with disease the findings are highly applicable to disease loss appraisal, and extensive reference is made to them on this account.

Seedling Disease, Stands, And Yields. -- Investigators of the control of seedling diseases by seed treatment have repeatedly observed that significant increases in stands resulting from seed treatments may not be followed by significant yield increases. This is usually due to use of an excessive seeding rate for treated seed, and most old standard seeding rates are excessive if seed is treated, sometimes extravagantly so. The effects of seedling disease are avoided by planting at such a heavy rate that even after considerable seedling mortality a fair to good stand remains. In such cases, if the seedling disease leaves no residual weakness in surviving plants, the loss is chiefly or entirely measured by the seed waste. If seed treatment tests are to be carried through to yield measurements, and if differences in yield, due to the treatment, are to be demonstrated, it is necessary to reduce the seeding rate to one that would produce a minimum satisfactory stand with treated seed and that would give a deficient stand with untreated seed. Differences in the degree of observance of this requirement evidently explain some of the discrepant results of the effect of seed treatment on yield.

In a similar fashion it is usually necessary to "plant for a stand" and avoid thinning the plant to a uniform stand in order to demonstrate the effects of seedling disease on yield. Where thinning the plants has commonly been the practice in the past, as in culture of cotton or sugar beets the yield losses from seedling disease are sometimes avoided by excessive seeding rates, and are not seen when lightly-thinned diseased stands are compared with heavily thinned healthy stan[ds] both eventually having equal numbers of plants per unit area.

In such cases, however, there may still be a difference in yields even though the stands fro[m] diseased and healthy plantings are thinned to equal numbers of plants. This is the result when seedling disease not only eliminates some plants but has a residual injurious effect on others, such as the "soreshin" of cotton which follows Rhizoctonia attacks on seedlings, so that the adult plants are never quite so healthy, although they are as numerous, as plants in a normal planting In this respect the effects of disease on yields differ from those of other causes of defective stands (birds, rodents, washing or blowing of soil, uneven planting, etc.), so that it is conservative to apply to disease loss appraisal the results of experiments with induced variable stands.

M^c^NEW (1943a, b, c, d, e), who has submitted some of the most useful data on seedling disease, seed treatments, stands, and yields for peas, lima beans, sweet corn, and spinach, has had the experience (1943e), for example, of securing almost equal stands from treated and untreated peas, 97.0 and 95.9% stands respectively, yet the yield from the untreated plantings was 9% (311 lbs./acre) less than that from the treated seed. In most of M^c^NEW'S other tests there was a high correlation between treatments, stands, and yields. PIRONE et al. (1933) observed

that with spinach, stand reduction and yield reduction were almost equal numerically, indicating either no compensation for missing plants by the remaining ones or a residual effect of the disease that offset the benefit of compensation.

There is another valuable source of data on seedling disease, stands, and yields in the work on sugar beets by AFANASIEV and MORRIS (1942, 1943), MORRIS and AFANASIEV (1945), and AFANASIEV (1945). Their experiments, in which the amount of seedling disease was controlled by fertilizer treatments, show that for every increment of 5% of disease there was approximately 3.5% reduction in yield. This is indicative of some compensation for missing plants, but the compensation effect may have been greater than could be detected because of the observed contrary yield-reducing residual effect of lasting injury in plants which survived disease attacks in the seedling stage but failed to develop normally.

In these cases in which yield increase, because of compensation, and yield decrease, because of residual effect of seedling disease, obscure one another, it would be possible to separate the two effects and measure each separately by suitable experiments. Compensation could be measured in healthy stands that are reduced by thinning, while the residual effect could be determined by comparing stands of equal density but consisting, respectively, of healthy plants and plants that have survived seedling disease.

Stand Variability And Yields Of Corn. -- The data on variable and depleted stands in corn, all of which are purely agronomic, make this a particularly well-documented example of stand-yield studies and their usefulness to disease loss appraisal. A number of investigators have found a good correlation between stand and yield in this crop, so reliable in fact that the relationship can be used in forecasting corn yields (Anon., 1947), and in calculating the theoretical yields of perfect stands, having only the data from imperfect ones (OLSON, 1928).

This relationship is not a numerically equal one unless the plants of a perfect stand are so widely spaced that each plant has all the space it can profitably use. More commonly they do not have this, and as a result, plants adjacent to a missing hill profit by this and produce yields somewhat above those of plants at normal spacing. If a normal, complete stand is taken as 100%, a 50% but fairly uniform stand will not produce 1/2 as much corn but about 2/3 as much, a 65% stand 4/5 as much, and a 90% stand 97% as much corn as the 100% stand (HUGHES and HENSON, 1930), because of compensation.

This relationship holds for stands in which the 100% stand is not planted at an excessive rate. OSBORN (1925) has shown that under favorable weather conditions corn stands and yields are correlated up to 9,000 or 10,000 plants per acre, but above this density yields fall, rather than rise, with increase in stand. The workers with corn have found that various corn varieties differ in their optimal densities of stand (cf. E. B. BROWN and GARRISON, 1923), and that for a given variety the optimal density varies with seasonal weather, being lowest under dry conditions (E. B. BROWN and GARRISON, 1923; OSBORN, 1925).

The extent of loss from missing plants and compensation by adjacent plants of corn is seen in the experiments of KIESSELBACH (1918) and of BREWBAKER and IMMER (1931). Where a 3-plant hill is considered normal, a 2-plant hill surrounded by normal ones yields 76-85% as much as normal: although the stand is reduced by 33% in this case, the yield is reduced by only 15-24% since the two remaining plants develop more strongly than they would in the normal presence of a third one. Similarly a 1-plant hill surrounded by normal ones has its yield reduced only by 40-74%, and with a single missing hill the reduction is not 100% of the normal yield of one hill, but only 67%.

Looked at from the opposite point of view, that of increased yield in the favored hills, a 3-plant hill adjacent to a 2-plant hill has 2.3% yield increase over normal, if adjacent to a 1-plant hill it is 5-9%, if adjacent to a single missing hill it is 13-15%, and if adjacent to two missing hills the increase in the 3-plant hill is 25-43% over normal yield, in the experiments of KIESSELBACH. Others report similar trends though with different numerical values, doubtless owing to different responses of types of corn and different environments. If weeds are permitted to occupy the positions of missing plants, the advantage of compensation may be largely or entirely lost, as has been observed in wheat (MACHACEK, 1943).

The investigations have shown that corn will tolerate a considerable amount of variability in stand without serious effect on yield, provided the total number of plants per acre remains constant. For example, KIESSELBACH (1922), and KIESSELBACH and WEIHING (1933), varied the number of plants per hill in different ways all of which gave averages of 3 plants per hill, and obtained yields for the uniform 3-plant-hill arrangement (3-3-3-3) of 59.0 bu./acre, for the arrangement 2-4-2-4, 59.2 bu., for the arrangement 1-3-5, 56.0 bu., and for the arrangement 1-2-3-4-5, 58.6 bu.

OSBORN (1925) who also found marked ability of corn to compensate for missing plants, has explained that this compensation takes the form of larger ears, more ears per stalk, and more tillers. A variety with a strong tendency to tiller may produce a stand of approximately 5000

stalks per acre from a 3000 seeding rate.

Effect Of Missing Or Diseased Hills Of Potatoes. -- Turning to the work with potatoes, much of which has been motivated by an interest in losses from virus diseases, we find a similar but more fully documented situation. The work was begun by FITCH and BENNETT (1910), followed by STEWART (1919, 1921), LIVERMORE (1927), and FOLSOM *et al.* (1931), all of whom found that when there is one missing hill in a row the adjacent plants on each side of the skip together make up about one half of the normal yield of a hill, leaving a loss of 1/2 hill. If the skip consists of two or more consecutive missing hills, all workers except LIVERMORE found that the adjacent plants fail to compensate for any more loss than 1/2 hill, so that a skip of 2 hills would be 1 1/2 hills loss, a 3-hill skip, 2 1/2 hills loss, etc. All investigators agree that the effect of missing hills is much influenced by soil, climate, and potato variety.

It is at once apparent that this compensation effect must be considered in evaluating losses from potato diseases. If adjacent plants compensate, to some extent, for missing hills they probably also compensate for hills of weak and sickly plants, and a comparison of hill yields, above all of yields of adjacent diseased and healthy plants, would exaggerate the loss from disease. The compensation effect will also be influenced by the arrangement of diseased hills among healthy ones, and it will decrease as the disease infestation approaches 100%.

This problem has been analyzed, mathematically and experimentally, in important studies of BLODGETT (1931) and BLODGETT *et al.* (1931). Healthy plants (H) and diseased plants (D) may be divided into 6 classes according to their arrangement in the row, with respect to the nearest two adjacent plants, as follows: HHH, DHH or HHD, DHD, DDD, DDH or HDD, and HDH. If p is the fractional part of plants diseased and $q = 1-p$, the frequency of these 6 classes for any given amount of disease is respectively q^3, $2pq^2$, p^2q, p^3, $2p^2q$, and pq^2. The yields of the middle plants in each of the 6 classes can be measured, and summation of the products of yield of each class by class frequency gives the estimated yield of similar potatoes with any given frequency of disease. Use of such a formula enables one to derive the loss from disease with full consideration being given to compensation effect and random arrangement of diseased and healthy plants in the field.

If this is applied to missing plants there will be only 3 classes (DHD, DHH or HHD, and HHH), since there is no yield from any class having D as the middle plant, which is the one measured for yield.

If there is 10% disease in the field the chance of finding a DHD combination is .1 (i.e., 1/10 chance of finding the first D) x .9 (the chance of finding the H after the D) x .1 (the chance of finding the D after the DH), or .9%. Using a similar procedure, BLODGETT (1941, Table 1) has calculated the percentage for each plant combination for 0, 10, 20, ...100% disease infestation.

Field studies with the potato leafroll disease, made by TUTHILL and DECKER (1941) using this method, have shown that healthy plants partly compensate for the losses in adjacent diseased plants, but that there is little or no difference in the low yields of leafroll plants, whether or not the adjacent ones are diseased or healthy. The more extensive field trials of KIRKPATRICK and BLODGETT (1943) showed that a healthy plant with a leafroll plant on one side (DHH or HHD) outyielded HHH by 16.8%, while leafroll plants gained 4.2 and 8.1% from having leafroll plants on one or both sides respectively. The effect of different percentages of leafroll in these experiments, calculated by BLODGETT'S method, is shown in Figure 27. The field studies have confirmed the view of BLODGETT that there is a basis for accurately appraising yield loss, with due consideration of plant arrangement and compensation effects, by determining the yields of the central plants in the 6 arrangement classes. This would seem to apply to nearly all tuber-transmitted potato diseases, to missing hills, and to any row crop where competition occurs between adjacent plants, and it has value either in evaluating loss or in estimating the disease-free yielding capacity of a variety even though fields of this variety have known percentages of disease.

Stands, Yields, And Compensation In Other Crops. -- Barley behaves like corn in having considerable ability to compensate for uneven spacing, with little difference seen in yields from evenly and unevenly spaced plantings (SPRAGUE and FARIS, 1931). Studies on the barley stripe disease, which causes total loss in affected plants (SUNESON, 1946), have shown a 3/4% yield reduction for each 1% of stripe, indicative of 25% compensation for deficient stands. With small-grains, which are not cultivated, there is a tendency for weeds to occupy the positions of missing plants, which prevents compensation for space and increases loss (SALLANS, 1948). The artificial removal of heads of small-grains is associated with a minor degree of compensation (HEUSER and BOEKHOLT *in* LUBISHCHEV, 1940). This has practical application in connection with head smut diseases such as bunt of wheat, where the yield reduction is slightly less than the smut percent (KIESSELBACH and LYNESS, 1939), although LEUKEL (1937) accounts for this by a more abundant stooling in infected plants rather than by compensation.

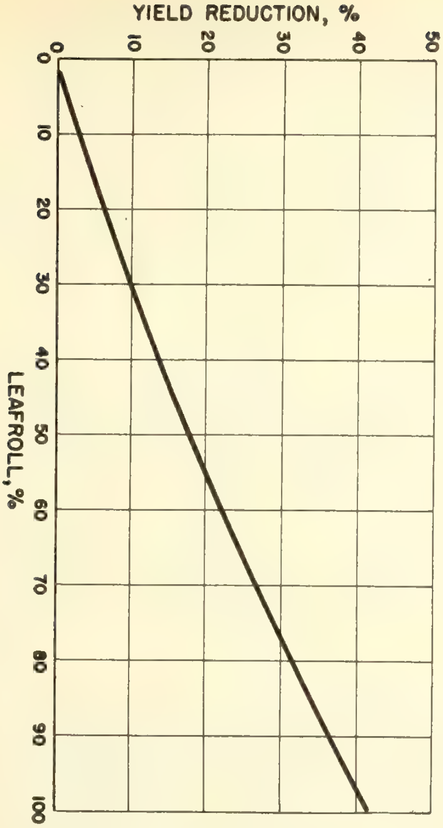


Figure 27. Relation between percent leafroll and yield reduction in three varieties of potatoes during three years. (From data of KIRKPATRICK and BLODGETT, 1943.)

With sugar beets, compensation for stand defects due to seedling disease was discussed on page 318. In contrast, the studies of WATSON et al. (1946) showed no compensation by adjacent beet plants for losses due to virus yellows.

Cotton, resembling corn and potatoes in its row culture, and being a crop in which stand defects are common, is a good crop in which to study the effects of stand variability. WARE and YOUNG (1934), who observed no loss from the killing cotton wilt disease (Fusarium) unless the wilt percent was 10% or even considerably higher, attributed this to compensation by healthy plants adjacent to diseased ones, but CHESTER'S (1946a) analysis of cotton wilt losses indicates that any amount of wilt causes some loss. Each increment of 5% wilt is associated with 3% loss, but this may be due more to the fact that wilt-infected plants produce some cotton than to compensation for this mid- to late-season disease.

A thorough study of the effect of missing row segments on cotton yields has been made by POPE (1947), who found that in single-row plots a three-foot skip is fully compensated for by the adjacent plants, while any skip longer than this causes a loss directly proportionate to the length of the skip, minus three feet. When skips are in a row bordered on each side by normal rows, the skips are largely compensated for by the plants at the ends of the skips and the plants in rows adjacent to the skips. Cotton is able to compensate for missing plants to a fairly high degree, and if a stand is uniformly thin, without long skips, there is little loss in yield as compared with that of denser stands.

The most outstanding cases of compensation for reduced stand are seen in forestry, where initial stands are far too dense to produce merchantable timber, and more or less radical thinning is regularly followed by space compensation by the remaining, marketable trees. The necessary thinning may be by various agencies, including natural hazards, suppression by the dominant trees, and selective harvesting. Disease is an important agency for thinning stands. This may be very harmful in the cases of those diseases of pure stands which destroy trees in patches up to several square miles in area. In other cases, much of the effect of the disease may be beneficial and necessary thinning, so that the loss is far less than indicated by the percent of trees destroyed. MEINECKE (1928) has reported, for example, that in one plot of pine 21% loss of trees from Comandra rust was a wholesome and beneficial thinning of an over-stocked stand, and even in a second plot where 65% of the trees were killed, the net result was to reduce the stand to only 32% below the Forest Service optimum.

FORMULAS OF DISEASE INTENSITY-LOSS RELATIONSHIPS: -- The expression "coefficient of injury (or damage)" has been used by various investigators with different meanings, in their attempts to find single numerical expressions of loss in relation to disease intensity. The "injury coefficient" of GASSNER and STRAIB (1936) is the percent reduction in yield for each week of duration of attack by disease (cereal rust) of a given intensity; for example, that of moderate stripe rust of wheat was 3%, and of severe rust 5%, yield reduction per week of rust infestation. The German workers consider these coefficients as conservative measures of rust damage, and recognize that the coefficients will vary with a given amount of rust in different environments, and in the same environment with differences in the extent to which the rust species interferes with the physiology of the host plant.

KLEMM (1940) has used the same term "injury coefficient" for the expression $Q = \frac{(a-b)\,100}{a}$ where a = yield of healthy plants and b = yield of diseased plants. The loss, $C = \frac{P.Q}{100}$ where P = the number of injured plants. Here Q is simply loss percent and P the percent of the crop affected.

In similar fashion, YACHEVSKI (1929) used a term "coefficient of damage" to express the relation of yield under definite conditions of disease (b) to yield of healthy plants (a), or $\frac{b}{a}$, with a maximum of 1 for a healthy crop, which, if multiplied by 100, would give the percent of a normal crop remaining after disease has taken its toll.

The "coefficient of damage" of LUBIMENKO (1933) is "that factor by which it is necessary to multiply the degree of damage to the vegetative organs in order to obtain the actual effect of the damage, i.e., the amount of loss in quantity and quality of the yield. This was used in artificial defoliation experiments with the form $\frac{\text{percent yield reduction}}{\text{percent leaf reduction}}$, and might equally well be applied to any disease that defoliates plants.

LUBISHCHEV (1940), who criticized LUBIMENKO'S "coefficient of damage" on rather untenable grounds, has introduced the concept of "threshold of injury", to indicate the maximum degree of injury, e.g., percent of leaves removed, that can be borne without loss in yield. This, regarded from the practical viewpoint, is an expression of the greatest amount of injury that is not accompanied by observed yield reduction and is more a measure of our ability to detect losses than of the plant to endure injury without loss. For practical purposes, 5% loss of leaves may be regarded as non-injurious but careful measurements show that any degree of defoliation has its effect, however small, in reducing yields.

Finally a fourth Russian worker, NAUMOV (1939), has given the expression "coefficient of injury" a still different meaning in his formula $R \frac{y}{x}$, where y = actual yield and x = amount of yield of diseased plants expressed as percent of theoretically normal yield. The values range from zero for a healthy crop to infinity for a completely diseased one. This is further developed, in studies of cereal rust damage, into a more complex formula involving tiller height from which NAUMOV indicates that regression of yield on any amount of rust infection can be calculated.

These several types of coefficients can be compared by making use of a concrete illustration. Suppose that a crop, which under disease-free conditions would yield 20 bushels per acre, is subject to a disease that destroys 30% of the leaves during a 5-week attack and reduces the yield to 15 bushels. KLEMM'S coefficient would be 25 (i.e., 25% loss), YACHEVSKI'S would be 75 (i.e., 75% of a normal crop), and NAUMOV'S would be .2 multiplied by some constant, which is not readily comparable to usual loss measures. LUBIMENKO'S coefficient would be 83.3 which relates leaf injury to yield reduction, the latter being expressed as simple percent loss (25%). GASSNER and STRAIB'S injury coefficient would be 5% loss per week of disease attack.

The coefficients of LUBIMENKO and of GASSNER and STRAIB are related to the physiology of injured plants and to the effect of disease in time, respectively, and therefore they have special uses apart from the main problem with which we are concerned, -- relating disease intensity to disease loss. The coefficients of KLEMM and YACHEVSKI are simplest and most understandable, and differ only in the point of view, -- whether attention is focused on the fraction of yield that was lost or the fraction of yield that remains. Neither, however, gives proper attention to disease intensity, as do the disease intensity-loss tables and regressions discussed below.

DISEASE INTENSITY-LOSS TABLES: -- Tables in which the approximate amount of loss is given for each of a series of disease intensities are useful devices for loss appraisal, but except in forest pathology very few of these have been made available. Best known, perhaps, is the table relating wheat stem rust severity at different stages of crop development to loss. This was prepared by the Office of Cereal Crops and Diseases of the U. S. Department of Agriculture and first published by KIRBY and ARCHER in 1927, and is here reproduced as Table 6. NAUMOV (1939) claims that this table does not apply to losses under conditions of wheat culture in Russia. CHESTER (1946b, p. 23) has presented a similar table for losses from wheat leaf rust.

LECLERG and his associates (1946) have published a table relating percent of virus-infected potato plants to reduction in yield of No. 1 tubers for five potato varieties and two virus diseases, spindle tuber and leafroll, each at seven intensities. The table shows some variation in loss between varieties and seasons but is nevertheless helpful in gaining an approximate indication of the losses from these diseases.

TIMBER CULL TABLES AND CURVES: -- The higher degree of development of forest disease appraisal than that of diseases of other crops is seen in the many useful tables and curves relating loss (cull) to observable indices of wood decay. Cull tables and graphs are developed by dissecting a large number of trees, correlating the decay found with external symptoms of decay and with

Table 6. Relation between wheat stem rust severity and loss in the crop (from KIRBY and ARCHER, 1927).

State of Development of the Crop						Loss from stem rust
Boot	Flower	Milk	Soft Dough	Hard Dough	Mature	Percent
. .	. .	. .	. .	(tr)	5	0.0
. .	. .	. .	(tr)	(5)	10	0.5
. .	. .	(tr)	(5)	(10)	25	5.
. .	(tr)	(5)	(10)	(25)	40	15.
(tr)	(5)	(10)	(25)	(40)	65	50.
(5)	(10)	(25)	(40)	(65)	100	75.
(10)	(25)	(40)	(65)	(100)	100	100.

size and age of tree, and formulating general relationships with stated, permissible degrees of error. The two examples given here serve to show the nature and value of these devices.

An excellent illustration of a well-devised cull table is given in a recent paper by ZILLGITT and GEVORKIANTZ (1948). The external symptoms are listed and described, including broken or dead limbs or tops, butt-rot, cankers, hidden rot, conks, cracks, crooks or sweeps, holes, ingrown bark, rotten burls, scars and seams. Each of these, where applicable, is divided into subgroups according to position of the defect within the merchantable length of a tree and according to condition or degree (large or small ; slight, moderate, or excessive; active or inactive). Then, for each symptom subgroup is given the percent of cull for 1-, 2-, 2 1/2-, 3-, and 4-log trees. To determine cull is a simple matter of multiplying the gross volume of the tree by the cull percent shown in the table for each defect present or the sum of cull percents in case of more than one defect.

An example of a somewhat different nature is found in HEPTING's (1941) study of the prediction of butt cull following fire. It was found that butt cull was highly correlated with width and age of fire wounds. An equation was developed from tree analysis data relating these three factors, and this is graphically illustrated in the curves of Figure 17 (see page 251), which were derived by multiple regression analysis. Aided by such graphs, cull volume can be estimated, with a practically sufficient degree of accuracy, knowing the age and width of the basal wounds.

As with other aids to loss appraisal, the cull curves and tables developed for a given species, habitat, and pathological situation, apply to stands and conditions of a similar sort but cannot be applied more generally unless it has been demonstrated that the disease-cull relationships have broader application.

REGRESSIONS OF DISEASE INTENSITY ON YIELD: -- Regressions, straight lines or curves depicting the relationship between disease intensity and yield, are among the most useful devices for translating disease into loss, and have been used very sucessfully in studies of the losses caused by numerous types of disease. A regression tells us, for each unit of disease intensity, the percent or amount of loss resulting.

The quantities related by regressions to yield may be any of the various measures of disease and include disease intensity as expressed in scale values, or indices, proportion of plants or plant parts occupied by disease, or time during which the crop has been exposed to disease.

When a regression of disease on yield is available, for any given disease intensity one can read off the amount of loss directly, interpolating between experimentally-determined points. If loss is measured in experiments in which different degrees of disease are compared but there are no completely healthy or totally diseased plants, the regression line can be extended to the zero and 100% disease points permitting one to determine loss values at disease levels beyond the range of those of the experiment, by extrapolation. If time or duration of disease is the quantity

related to loss, the regression gives the basis for forecasting loss, as has been done with sugar beet yellows (WATSON et al., 1946).

While regressions are convenient ways of expressing disease loss relationships, they are only as valid as the data from which they are derived. We have seen that disease intensity-loss relations may vary with variety of crop, strain of pathogen, and environment in which disease develops. The regression of disease on yield derived from data that apply only to certain limited conditions, will itself have application only to those conditions. Fortunately, many of the findings of loss appraisal experiments have rather wide application within the range of error that is permissible for loss estimation (cf. pp. 220-221).

The methods of deriving regressions and testing them for significance and for linearity are to be found in standard works on statistical methods. A good illustration of their use is found in GREANEY'S (1933b, 1934) studies of the effects of stem rust on yields of wheat and oats, based on sulfur-dusting experiments. His regressions of yield on percent stem rust are reproduced in Figure 28.

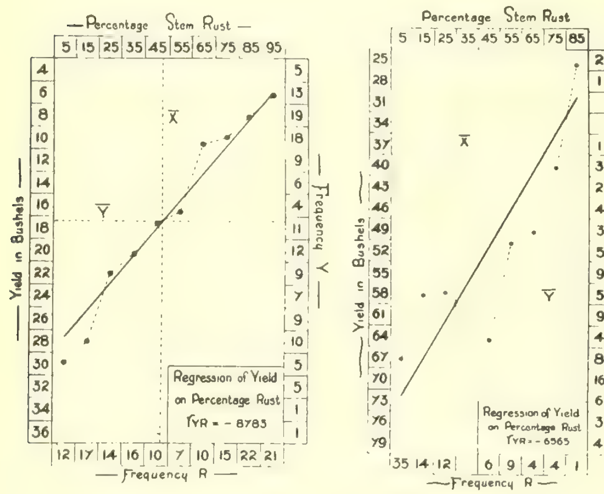


Figure 28. Regression of grain yields on percentage stem rust according to the modified COBB scale. Left: Marquis wheat. Right: Victory oats. From 1930 experiments of F. J. GREANEY (1934).

In this, as in numerous other studies, it has been found that the regression is linear, i.e., an increase from 10 to 20% rust decreases the yield by the same amount as an increase from 70 to 80% rust.

In the study of wheat, the regression showed that each 10% increase in rust resulted in a 2.1 bushel per acre decrease in yield, representing 6.9% of the possible yield, while with oats each 10% of rust lowered the yield by 4.7 bushels, representing 7% of the possible yield. In both cases the correlation coefficients were high (-0.88 and -0.66) with odds for significance much greater than 100:1.

When a study is made of several factors each of which simultaneously affects yield, the partial regressions of yield on each factor can be calculated, making this a useful manner of determining the relative effect of each factor influencing yield. This was the method used, for example, by SALLANS (1948) in distinguishing the effect of preseasonal rainfall, June-July rainfall, air temperature, root rot, insect damage, and yield of wheat. It showed that for each increase of one unit of root rot intensity there was a decrease of 0.583 ± 0.203 bushels per acre of yield, a drain on the crop equalled only by that of deficient rainfall in June and July.

Using regressions one can analyze a series of interwoven factors related to disease and yield as was done by WIANT and STARR (1936) in work on bacterial wilt of alfalfa. The wilt problem is interpreted through regressions of wilt on stand, wilt on age of field, age of field on stand, and wilt on winter injury lesions. This study shows that not all disease-yield regressions are linear. That of wilt on age of field is practically linear, with an increase of approximately 12% of plants affected each year from the first to the fifth years of stand age, and then becomes horizontal, with little increase in wilt percent from the fifth to eighth years. This change is explained by the death of diseased plants after the fifth year, which eliminates plants at the same rate at which new cases of disease occur. The regression of wilt on winter injury lesions is a curve in which each increment of lesions is associated with a greater increment of wilt than the preceding increment of lesions.

Other studies that illustrate the usefulness of analyzing disease intensity-yield data by use of regressions are those with the cereal rusts by GOULDEN and ELDERS (1926), GREANEY et al. (1941), and WALDRON (1928), with loose smut of barley by SEMENIUK and ROSS (1942), and with cereal root rots by MACHACEK (1943) and SALLANS and LEDINGHAM (1943).

The literature on plant diseases and their effects on yields contains many raw data that would be suitable for analysis by use of regressions, although this has not been done in the published reports. An example is the body of data on potato leafroll and yields published by GRAM (1923). "Healthy" (somewhat diseased) and "diseased" (somewhat healthy) potatoes were planted at each

of 12 locations in Denmark during 5 years, the seed tubers for each year being those harvested from the experiment the preceding year, with much variation in disease percent from year to year. On inspection the data appear so heterogeneous as to defy interpretation, nor did GRAM attempt to interpret them from the standpoint of disease loss but only from that of annual disease increase. There is no zero point and no 100% disease point, but instead many comparisons of yields of stocks with greater or less disease intensities, under different environments.

J. H. McLAUGHLIN (unpublished) analyzed these data by the regression method and obtained the highly significant coefficient of correlation between disease percent and yield of $r = -0.9369$. A linear regression fitted the data best and this showed that for every 1% increase in leafroll there was a decrease of .1599 centners per hectare which approximately equalled a 0.67% yield decrease. This value is in good agreement with independent measurements of loss from leafroll. The analysis by locations and by years showed that the intensity-loss relationships were more constant between locations in any one year than between years at any one location.

McLAUGHLIN'S analysis of GRAM'S data is an important technological contribution in showing how data that were not intended for loss study may be useful for this purpose, how apparently heterogeneous data yield to analysis by the regression method, revealing highly significant disease intensity-loss relationships, and how additional conclusions to those drawn by the author, in this case on the epiphytology of the disease, are brought out by approximate analysis.

The success seen in this example indicates the fertile source of disease loss information that lies hidden in many papers comparable to that of GRAM, and suggests the value, to the student of loss appraisal, that lies in a search for such data and their appropriate analysis.

EXTENSION OF LOSS CALCULATIONS TO LARGE REGIONS: -- In summarizing disease loss data for States, Provinces, or countries, either of two practices may be followed. The disease intensities for numerous sub-areas may be averaged, with weighting for the crop acreages of the sub-areas in the fashion described on page 256, and the final mean disease intensity may then be converted into terms of loss. More commonly, when the object is to determine total loss for a region, disease intensities for the sub-areas are converted into terms of loss, in percent or in units of production, and the individual losses are summated or averaged, weighting for the sizes of the crop areas involved, to give a single figure for total loss.

In the annual loss summaries of the Plant Disease Reporter a standard, common practice of loss summation is used. This is described in Supplements 6 (1918), 12 (1920), 83 (1932), and 94 (1936) of the Reporter. In calculating losses it is considered that:

$$\text{Possible production} = \frac{\text{Actual production}}{100\% - \%\text{ loss from disease (s)}}$$

The loss caused by disease is then taken as the product of possible production x percent disease loss. If disease is causing a 50% loss in a crop that actually produced 1000 bushels, the loss is not 500 but 1000 bushels, because the 1000 bushels was only half a crop; a 100% crop would have been 2000 from which 50% disease loss subtracted 1000 bushels, leaving 1000. The fallacy of determining loss by multiplying actual production by percent loss is sometimes encountered; this fallacy is avoided by using the technique followed by the Plant Disease Reporter.

In calculating the mean percent loss for the United States the loss for each State, in production units, is determined as above, and these are totalled and divided by the possible national production in the absence of disease. Examples of these calculations are given in Supplement 83 (1932) of the Plant Disease Reporter. The loss estimates are expressed in percent of crop loss or in production units but never in dollars "because of the complex economic considerations which this would involve". (This point is discussed on page 342).

Essentially the same method of summarizing national losses from disease has been used by the German plant protection service (MORSTATT, 1929, 1937). An example of use of this method in a special survey is seen in H. D. BROWN'S (1929) determination of the loss caused by *Septoria* leaf spot in the Indiana tomato canning crop. All fields examined were classified as healthy or in two degrees of disease. Actual yields of fields of the three types were ascertained and the differences between yields of diseased and healthy fields gave a measure of loss in tons of tomatoes. Knowing the total inspected acreage, the actual yield of the inspected fields, and their possible yield (total acreage x acre-yield of healthy fields), the loss in percent could be readily calculated, and from this loss percent and the actual State yield BROWN determined the possible State yield and the State loss in tons and dollars.

A comparable practice is illustrated in appraisal of the damage done to the Texas cotton crop by the root rot disease, reported by EZEKIEL (1938). Many cotton fields were scanned from the roadside and the loss percents estimated. These were averaged for each county, weighted for the

cotton acreage of the county, and combined to give the State loss in percent and bales.

GREANEY'S estimates of cereal rust losses in Canada (1933a, b, 1936) represent use of the method of summarizing disease intensities and finally converting these into summarized loss estimates. Having determined the regression of yield on percent rust, he was able to translate any given rust intensity into percent loss. Then, having ascertained the average rust intensities in numerous sub-areas from the Canadian plant disease survey data, and the actual production from the Provincial Departments of Agriculture, it was a simple matter to convert disease intensity to loss in percent, bushels, and dollars, on a national scale.

An analogous practice was used by HORSFALL (1930) to estimate losses from meadow crop diseases in New York. It was first determined in the case of Macrosporium leaf spot of red clover, for example, that each 1% of leaf spot infection results in a 0.25% hay loss. Next the mean percent of infection for the State was estimated by summarizing the individual products of acreages x infection percents and dividing by the total acreage. Finally the loss percent corresponding to the mean infection percent was applied to the State yield to give the State loss in tons and dollars.

APPLICATION OF LOSS RATIOS TO DISEASE INTENSITY DATA: -- The foregoing illustrations show how the disease intensity-loss ratios, derived by experiment, can be applied to data on disease intensity to give reliable estimates of loss in terms of percent, production units, or financial loss. By far the greater part of recorded plant disease survey data is in the form of disease intensities. As more intensity-loss ratios are determined, we can go back through the records of disease intensity and convert them into loss estimates. GREANEY'S regressions of cereal yields on stem rust, for example, can be applied not only to current rust attacks but also to rust outbreaks of past years, as far back we as have any reliable information on rust intensity, giving us a record of losses down through the years. The same can be done with the loss ratios that have been derived for cotton wilt, root rots of cereals and cotton, virus diseases of potaotes and sugar beets, and any other disease for which we have such ratios. The planners of agricultural progress think in terms of decades or greater fractions of centuries, and the value to them of having the costs of agricultural hazards on a comparable basis is patent.

We are just at the beginning of this important application of plant disease appraisal. Few disease intensity-loss ratios have yet been derived and many more are needed. Fewer still are the cases in which these ratios have been applied to the disease intensity data of past years. The only two instances of this that have come to hand in the course of the present study are in connection with GREANEY'S work with cereal stem rust and BUTLER'S (1940) application of his wheat leaf rust intensity-loss relationship, derived from sulfur dusting experiments, to earlier New York rust data. The derivation of loss ratios and their use in converting recorded disease intensities to loss estimates is one of the most promising methods that can be suggested for obtaining extensive and reliable loss data with minimum labor and cost.

Chapter XI

FORECASTING PLANT DISEASE OUTBREAKS AND LOSSES

Science is concerned with the discovery of causation of natural events, and when the principles of causation are sufficiently well known, science reaches its goal of permitting the accurate prediction of events on the basis of known antecedent circumstances. The study of disease appraisal is no exception. Any instance of the estimation of disease intensity and conclusion, based on experiment, that this disease intensity will result in that given degree of loss, is a prediction from cause to effect, a legitimate application of the scientific method. In plant disease appraisal, this usage reaches its highest development when a knowledge of disease intensity-loss relationships is combined with an understanding of the progressive changes in disease intensity itself, permitting one to predict accurately that the pathological situation of the moment will be followed by certain developments in disease intensity, and that these, in turn, will result in a given degree of loss.

The subject of plant disease forecasting was mentioned in Chapter I (p. 207) where the economic value of such forecasts was pointed out. Here we are concerned with the methods and accomplishments of disease forecasting.

PLANT DISEASE IN YIELD FORECASTING: -- Forecasting plant disease intensities and their effects is a special branch of the subject of yield forecasting. In the past, the forecasting of crop yields has been largely guesswork by men varying widely in knowledge of crop conditions and in judgment. As a result, yield forecasts are often far from correct, even when made just before crops are harvested. Faulty estimates are almost invariably "explained" in terms of decisive influences of late-season weather which could not have been foreseen, rather than in terms of ignorance of, or misplaced emphasis on, the more truly decisive early-season influences.

Recently attempts have been made to substitute science for intuition in yield forecasting. Two elements have aided in this: the establishment of correlations between early-season crop characteristics and yield, and the use of long-range weather forecasts to take some of the guesswork out of the late-season weather factor. The scientific forecasting of yields is a major project of the Iowa State College Statistics Laboratory, and good progress has been made in increasing the accuracy of the corn yield forecasts by basing early predictions on seasonal development, soil moisture, stand counts, stalk size, ear counts, and measurements of ear size, with correction based on the long range weather forecasts (Statlab Review, Sept., 1947 and May, 1948).

In a similar fashion, CROWTHER (1941) has evolved scientific methods for forecasting cotton yields, based on a study of correlations between yield and leaf nitrogen of seedlings (a reflection of soil fertility and index of potential growth vigor), plant height, internode length, number of blossoms, leaf and stem dry weights and nitrogen content, defoliation, and degree of infection by the black-arm and leaf-curl diseases.

For the most part, attacks by insects and plant diseases have not been considered in yield forecasts except as unpredictable hazards that might explain incorrect forecasts. Their inclusion would go far in contributing to more accurate yield forecasts. It is not entirely that these hazards have been overlooked nor are they entirely unpredictable. This defect is due in an important measure to the fact that plant pathologists and entomologists have not provided the basic information relating environment, disease or insect intensity, and ensuant losses, that would permit the inclusion of these hazards in yield forecasting.

THE BASIS FOR PLANT PEST FORECASTING: -- Contrary to lay opinion, outbreaks of plant pests do not suddenly occur without warning. Forty years ago SORAUER (1908) called attention to this: "In all endemics and epidemics a simultaneous sickening of a great number of individuals indicates a considerable period of preparation leading up to the actual outbreak of the malady..... Each epidemic is, so to speak, the explosion of a charge which has been slowly accumulating for some time." With plant pests as with political movements, ascendancy is a surprise only to those whose eyes have been closed to the progressive development of the pest or ideology, from small to ever larger proportions.

The basis of plant pest forecasting is a careful, thorough study of the survival of pests and the early stages of their seasonal increase. This has been stressed in studies on the forecasting of wheat leaf rust outbreaks (CHESTER, 1946b, p. 151-152). It has been shown that destructive rust outbreaks must be preceded by many generations of rust increase, weeks or months before the disease becomes apparent to the layman. If these early generations occur, subsequent destructive rust is inevitable, and if they are inhibited there is not sufficient time in the remainder of the growing season for rust to increase to damaging extent. The early generations of rust in-

crease are not readily apparent, and it may require long hours of search and counting to chart the course of rust development early in the growing season, but if this is done it permits reliable forecasting of rust long before harvest time, as has been shown by the accurate wheat leaf rust forecasts of the past decade.

Together with observations on the development of plant pests, forecasting requires a knowledge of the effects of environment on their increase, so that long-range weather forecasts may be applied to future pest increase. In the case of wheat leaf rust again, enough is known of the relationships between temperature, moisture, and rust development to give assurance that once a certain date has been passed (April 1, in Oklahoma) the odds are highly against weather that will interfere with rust increase, the course of the disease in late season being chiefly dependent on early-season weather. For purposes of disease forecasting, DOROGIN in Russia (in YACHEVSKI, 1929) considers it necessary to have information on air, soil surface, and subsoil temperatures and humidities, amount and type of precipitation, cloudiness, depth and duration of snow cover, and strength of prevailing winds, and to know the effects of these factors on the disease in question. It is self-evident that the particular types of information on environment that are needed for forecasting will vary from one disease to another.

DISEASE TEMPO AND FORECASTING: -- Forecasting plant disease intensities and losses is materially aided by knowledge of the tempo of disease development, a subject discussed on pages 234-237. Disease tempo is an expression and a resultant of the interplay between reproduction of pathogen, environment, and host plant response. From a study of disease tempo under given conditions, it becomes possible to predict that under similar conditions in the future the intensity of disease will progress in a similar manner, and to predetermine the intensity of the disease at any given future time. Where disease tempo depends on unpredictable future conditions, a knowledge of this fact brings out the limitations of reliable forecasting.

Some diseases progress at a fairly regular rate that is relatively insensitive to normal weather fluctuations. In such cases the tempo is expressed by the regression of disease intensity on time, and the forecast of disease intensity at any given time in the future can be read directly from the regression line. The table of losses from wheat stem rust of KIRBY and ARCHER (1927), reproduced on page 323, is based on the assumption that rust intensity increases with time at a regular rate, and, to the extent that this assumption is correct, it permits forecasting both future rust intensity and ultimate loss. Similarly, the linear regression of loss on symptom expression with sugar beet yellows (WATSON, et al., 1946) can be used in forecasting yields and enabling beet factory operators to make appropriate provision for receiving the crop.

FORERUNNERS OF THE UNITED STATES WARNING SERVICE: -- In America current interest in plant disease forecasting centers in the warning service of the U. S. Plant Disease Survey, an outgrowth of the potato and tomato late blight forecasting developed during World War II. It does not appear to be commonly known in America that forecasting or warning services for potato late blight and downy mildew of grape were initiated in Europe a quarter-century ago and became highly developed during the 1930's.

In France and Italy, the vine mildew warning service developed in parallel fashion, with networks of observation stations and wide publicity of warnings of imminent mildew attacks. In Germany spray warnings were based on MÜLLER'S "incubation calendar", while in Russia this calendar was variously modified to adapt it to local conditions. In the discussion that follows, to avoid unnecessarily extensive citation of papers, references are limited to those of abstracts of the papers in the Review of Applied Mycology, by volume and page.

VINE MILDEW FORECASTING IN EUROPE: -- As early as 1922, a vine spray warning service had been organized in Italy (R.A.M. 2:6; 4:526; 8:150; 9:158; 10:21; 11:692; 12:73, 199; 15: 735; 16:86, 152, 230, 513). Meteorological conditions likely to influence disease outbreaks were reported from stations in three Provinces and forwarded to Turin where the data were compiled and, as soon as the information indicated favorable conditions for spore germination and infection spray warnings were widely published. Responsible farmers, as well as trained personnel, served as observers. By 1929 there were 53 observatories in the province of Alessandria alone, and the warnings were saving large sums of money in avoiding needless spraying, yet protecting the vineyards when conditions were favorable for the disease. That year the program was extended to the Province of Treviso on an experimental basis, which later proved entirely practical. A similar warning service was urged for southern Italy, and one was organized in Sicily in 1936.

The observatories were provided with equipment for measuring temperature and moisture, and the data included direct observation of condensed water, which is most important for spread of the disease by zoospores. While there were some discrepancies between weather reports and

subsequent disease at different stations, the practical utility of local forecasting was not considered dependent on correlation of data between stations. Growers were advised that spraying begin when the first infections showed as "oil spots".

The French vine spray warning service operated over the same period as that in Italy (R.A.M. 3:468; 9:85;430, 761; 10:581; 11:622; 12:72; 13:149; 14:77, 420; 16:513; 19:5; 24:460; 25:382, 434). Reference is made to a forecasting station in Cadillac where the critical times for infection had been studied since 1898, one initiated in Bordeaux in 1922, an important station at Montpellier, and others at Clermond-Ferrand, Avignon, and Antibes. The Montpellier station received data from 59 outposts in the Montpellier region and others from France and abroad by wire, or, in the earlier days, the reports were relayed by visual or sound signals, and daily code telegrams were issued to subscribers of the warning service giving information on the appearance of pests, spray warnings, and weather. These telegrams received a priority at a reduced cost. In 1931 the Bordeaux station had 1, 425 subscribers.

The French vine mildew forecasting and warning service, which proved to be generally accurate and which resulted in important savings of crops and spray expense, was based on extensive studies of the interrelation between weather, fungus, and disease. At Montpellier the method of forecasting was based on growth stage of the crop and developmental stage of the fungus. Primary invasion was determined by oospore germination, with the incubation periods considered to be regularly nine days for the first cycle and seven days for the later cycles. Germination of the overwintered oospores under natural conditions was used as an index of the time of spring renewal of the disease. At Bordeaux it was considered that the earliness and intensity of infection are determined by the November-April rainfall, with secondary cycles dependent on spore prevalence and amount of rain. This permitted forecasting mildew outbreaks long in advance. A combination of the two methods was used at Clermont-Ferrand. The Italian method of waiting until the first infections appear as "oil spots" was considered unreliable in France.

The French workers have made interesting use of phenology in connection with spray warnings. Finding that the first attack of sycamore by the anthracnose fungus, Gnomonia veneta, regularly precedes the first attack of the vine mildew by several days, the sycamore disease is used as an index of imminent vine disease.

The French forecasting and spray warning service has given good practical results, frequently reducing the empirical five to six spray applications to one or two, with important conservation of spray materials during times of shortage.

In Germany (R.A.M. 10:432; 13:678; 16:654; 17:292) vine spray warnings have been based on K. MÜLLER'S "incubation calendar", which was developed in 1913 and which is claimed to have averted immense losses and more than doubled grape yields in the Baden area over a 19-year period. The incubation period of mildew was found to vary from 5 to 18 days, depending on the weather, and the "calendar" was a guide to timely spraying based on temperature and moisture and their effects on the future development of the disease. The French workers have considered that use of the "calendar" requires great care on the part of growers who generally cannot make the necessary observations, and that the method must be supplemented by others. It is also believed to be of limited reliability in Switzerland (R.A.M. 19:325).

In Russia (R.A.M. 11:93; 14:9; 15:279, 702, 773) MÜLLER'S "incubation calendar" has been found useful if adapted to local conditions, and vine mildew forecasting is considered feasible on this basis. The modified formula for the incubation time in Russia is given as $h\ (t-8) = 60$, in which h is the number of days of the incubation period and t is the average mean daily temperature for the period. This is useable between 10° and 24° C., but at the lower range greater precision results from use of the formula $h = \frac{60\ (t-8)}{(t-16)\ 64D}$ where h is as above, t is the mean day temperature on the day on which infection occurred, and D is the increase in mean daily temperature for 30 days; t and D are obtainable from the long-term weather records. A second Russian method determines the average lenth of the incubation period as 61° ÷ the average daily "effective" temperature (which is the actual temperature minus the "critical temperature" or minimum point below which the fungus is suppressed).

POTATO LATE BLIGHT FORECASTING IN EUROPE: -- Forecasting and spray warning services for potato late blight evolved independently in Holland, England, France, and the United States. Holland led the way when, in 1926, VAN EVERDINGEN (R.A.M. 5:627) proposed his four rules governing the appearance of late blight. Development of the disease, according to the Dutch rules, required (1) a night temperature below the dew point for at least 4 hours, (2) a minimum temperature of 10° C. or above, (3) mean cloudiness the next day of 0.8 or more, and (4)

at least 0.1 mm. of rain during the next 24 hours. Provision for control measures was recommended only after days fulfilling all four of these conditions.

Answers to questionnaires sent out by the Dutch Phytopathological Service in 1926 confirmed the reliability of the Dutch rules, and arrangements were made for the Royal Dutch Meteorological Institute at Te Bilt and its observatories in the potato-growing sections to issue blight warnings that were broadcast with the weather reports and issued through the press (R.A.M. 7:664). Later reports from Holland (R.A.M. 9:15; 11:96; 14:11, 715; 18:153) describe in more detail the "cautionary service" and indicate the very satisfactory results from the service.

Between 1929 and 1933 the Dutch rules for late blight forecasting were tested in England and found to be generally satisfactory, though with occasional irregularity (R.A.M. 9:623; 11:123, 558). BEAUMONT and STANILAND then proposed a 5-rule modification in which a day was counted as favorable for blight if: (1) there was dew either the night before or in the morning, (2) the minimum temperature was 50° F. or above, (3) there was less than 5 hours of sunshine, with (4) at least 0.01 inch of rainfall, and (5) a relative humidity at 3:00 P.M. higher than 75% (R.A.M. 13:8, 561; 14:676; 15:555). These rules worked well in Devon and Cornwall but were later simplified (R.A.M. 16:514; 17:583) to two rules: (1) minimum temperature lower than 50° F. and (2) relative humidity greater than 75% for two or more days. These two rules provided the best of the several forecasting methods tried and were used thereafter in the British warning program.

The French system of observatories and spray warning service has been described in connection with vine mildew. The same system was used for other diseases including potato late blight. At first the simple method was followed of issuing warnings on the appearance of the disease. (R.A.M. 12:75; 13:149). There was difference of opinion as to whether either the Dutch rules (R.A.M. 13:76; 14:189) or the British ones (R.A.M. 18:814; 25:469) applied to French conditions. No new system was proposed, though it was urged by DARPOUX (R.A.M. 24:459) that thorough study be made of the ecology of disease organisms to permit more rational forecasting and spray warning. The French appear to be the first to have used the method, later developed by MELHUS in the United States, of planting late-blight-infected tubers in disease observatories so that absence of disease development could not be ascribed to lack of inoculum (R.A.M. 25:328).

In Germany, during this period, the principal contribution to late blight forecasting was the basic study of the environmental relations of the blight fungus by MÜLLER (R.A.M. 10:545) and ORTH (R.A.M. 17:57). In Russia the Dutch rules proved valid in the Leningrad region though subject to correction in other areas, and a nomogram was prepared to aid determination of the length of the incubation period of late blight, knowing the maximum, minimum, and mean temperatures (R.A.M. 15:522).

POTATO AND TOMATO LATE BLIGHT FORECASTING IN THE UNITED STATES: -- Potato late blight forecasting in the United States has had its foundation in the basic studies on the epiphytology of the disease and the environmental relations of the causal organism, of MELHUS (1915), NAPPER (R.A.M. 13:260), and CROZIER and REDDICK (R.A.M. 13:724; 14:391; 15:45). The critical temperature above which late blight does not develop was determined as 73.7° F. by MARTIN in 1923 (R.A.M. 3:173) and for practical purposes was later regarded as 75° F. by collaborators of the Plant Disease Survey. THOMAS (R.A.M. 25:470) emphasized the importance of microclimate in the "foliarsphere" about the potato plant, in contrast to conditions at the ordinary level of weather instruments, in determining disease development. TEHON (R.A.M. 8:327) devised graphic methods for defining the meteorological conditions permitting disease outbreaks, applying them in particular to potato late blight.

The first regular potato spray warning service in the United States was inaugurated in Maine in 1931. Eighty-one growers cooperated and this number increased to 2,410 in 1933 and 3,000 in 1934. In 1937, W. D. MOORE (R.A.M. 16:831) in South Carolina analyzed the weather record of the past 20 years in relation to late blight and concluded that it should be possible to predict outbreaks, which would be expected when March, April, or May had at least 3.5 inches of rain distributed over 9 days or more, with 5 or more days having 0.2 inch or more of rain. Plans were laid for late blight prediction on this basis.

One of the forerunners of the nationwide disease forecasting service in the United States was initiated by I. E. MELHUS, chairman of a wartime committee on potato late blight. In 1942 he proposed a plan for forecasting the disease, based on a 27-year analysis of Iowa weather and late blight outbreaks. The plan involved planting infected tubers at many points, with subsequent observation of blight development and weather, assembly of data at a central point, and dissemination of forecasts and spray warnings by all effective means of publicity.

The plan was put into operation throughout the upper Mississippi Valley in 1943 (MELHUS, 1945) following a 25,000,000 bushel loss from potato late blight the preceding year. The forecasts

were based mainly on the assumption that late blight will be severe, in that region, if June-July average temperatures are above 70° F. This project, along with some other, informal, reporting services, was merged with the Warning Service of the U. S. Plant Disease Survey in 1947-48.

Meanwhile, HAROLD COOK in Virginia (1947, 1948a, b) had been independently studying the problem of forecasting late blight in potato and tomato, through a 17-year analysis of weather and blight. The critical rainfall line, above which the amount was favorable for blight and below which blight was inhibited, was obtained by plotting a cumulative seasonal rainfall line midway between the lines representing the mean rainfall in blight years and in blight-free years. The critical temperature for blight was similarly taken at 75° F. Blight could be predicted with 88% accuracy when the temperature was below and rainfall above the critical levels. A moving graph of 7-day average rainfall and temperatures proved most accurate for analyzing late blight-weather relationships over an entire season. In 1947 the forecasts in Eastern Virginia made possible a saving of $2,000,000 in potato and tomato spray costs.

UNITED STATES PLANT DISEASE WARNING SERVICE: -- The stage was now set for the initiation of a national plant disease forecasting service. In November, 1946, a year of destructive late blight, the National Canners' Association and the Indiana Canners' Association recommended that a tomato and potato blight warning service be established in 1947. The following month the Plant Science Technical Committee urged the U. S. Department of Agriculture to consider carefully the possibility of organizing a forecasting service. The same month the American Phytopathological Society resolved that "in view of the heavy losses sustained by American agriculture from sweeping outbreaks of plant diseases, the Society considers that one of the most important services needed by American farmers is a more effective reporting and forecasting service and a vigorous program of research basic to such a service", and solicited the aid of agricultural research administrators toward this end.

The need for a forecasting service was clear and the demand for it was evident. Just at this time the United States Congress passed the Research and Marketing Act (Flannagan-Hope Bill) authorizing cooperative agricultural research on a regional basis among States and between States and the Federal Government. This provided an ideal implementation for a national and necessarily cooperative disease forecasting service.

The Forecasting Project, as approved under the Act, was an experimental program designed to investigate the practicability of regional forecasting of plant disease occurrence, with special reference to late blight of potato and tomato, tobacco blue mold (Peronospora tabacina), and cucurbit downy mildew (Pseudoperonospora cubensis), and to conduct research on the factors in disease development that are basic to forecasting. Three plant pathologists were added to the Survey staff, stationed in three regions for the experimental developmental studies in cooperation with the States comprising each region, with the Survey acting as coordinator. The current reporting, or "warning service", after its practicability was demonstrated, became a function of the Survey proper. The Survey serves as clearinghouse for receiving and relaying timely reports on the development of the warning service diseases, with the cooperation of State key pathologists. The key pathologists, in turn, are responsible for furnishing information to the Survey, and for whatever publicity or recommendations may be warranted in their own States. Accounts of this organization have been published by P. R. MILLER (1947a, c), MILLER and PERSON (1947), and MILLER, WOOD et al. (1947). Through cooperation with the Weather Bureau, the semi-monthly weather outlook is sent to cooperators, who have found it invaluable in extending the time range of their forecasts.

Thus the work of the Forecasting project, as originally established, has become divided into the "Warning Service" proper, and the research project on the epiphytology of the diseases concerned. Cooperators report to the warning service on an entirely voluntary basis. Disease spread plus weather constitutes the guide to forecasting, but meteorological rules for the variable, wide-range conditions of the United States and Canada remain to be worked out and tested. Extensive and successful use of the more exact method abroad indicates eventual development of similar procedure here. The long-established potato late blight forecasting services of Holland, England, and France furnish invaluable foundation material, but their experience is not wholly applicable under our conditions. Except for its proven usefulness the warning service, therefore, is still largely experimental, as far as its basic criteria for prediction are concerned.

FORECASTING CORN WILT: -- The prediction of disease outbreaks has proven reliable and useful with a number of other types of disease. Pioneering in this work was NEIL STEVENS, who established a correlation between winter survival of adult flea beetles in the bodies of which the corn wilt (Bacterium stewartii) bacteria hibernate, winter temperatures, and outbreaks of wilt the following spring. For several years STEVENS accurately forecast severity of the dis-

ease, basing his predictions on December-February temperatures, in time for growers to avoid losses during wilt years (STEVENS and HAENSELER, 1941).

FORECASTING CRANBERRY KEEPING QUALITY: -- STEVENS (1943) also forecast the keeping quality of cranberries in Massachusetts from 1923 to 1928, with accurate results in all but one case; in this case decay was due to abnormal harvesting practices. The predictions were based on the observation that most serious fruit decay occurs in years in which May and June are warm and July and August are wet, with less loss when only one of these conditions prevails and least loss when May and June are cool and July and August are dry.

FORECASTING APPLE SCAB: -- Forecasting the time of primary infections of apple trees by the scab fungus has now become a standard practice underlying spray warning services in leading apple production areas. During late winter and early spring, the sexual fruiting bodies of the scab fungus in overwintered dead leaves gradually mature. Periodic examination of these leaves reveals the time at which the first spores of the fungus are about to be shot out of their containers, in condition to initiate infection, and this information is put to good use in determining the best time to begin spraying.

FORECASTING WHEAT LEAF RUST: -- During the past decade the writer and his associates in Oklahoma have developed a basis for forecasting the severity of wheat leaf rust and have used it successfully in rust forecasting nine years (Plant Disease Reporter 26: 213-217, 1942: Supp. 143, 1943; 28:280-287, 1944; Supp. 156, 1945; 30:162-165, 1946; 31:201-202, 1947; 32:176-181, 1948; 33:223-226, 1949). Two of the forecasts were of serious epiphytotics (1938, 1945), two were of abnormally light rust development (1944, 1948), and the others (1939, 1941, 1946, 1947, 1949) were of no more than normal rust injury. In all cases the outcome in Oklahoma was as anticipated, and usually the condition of rust which was forecast for Oklahoma had its counterpart throughout much or all of the wheat areas to the north. Issued usually on April 1 of each year, the forecasts have aided farmers and grain elevator operators in planning for harvest and disposal of the crop, and in some cases they have been decisive in determining whether to allow crops of borderline condition to go to maturity or, alternatively, to abandon the wheat in favor of spring-planted summer crops.

Since 1942 the forecasts have been based on an intensive analysis of the overwintering and early spring renewal of rust, correlated with late winter and early spring weather conditions, and an extensive survey the last week of March to determine whether the findings of the intensive study have statewide application. The basis of forecasting lies in the facts: (1) that in Oklahoma the weather from April 1 onward rarely if ever is a factor limiting rust development, (2) that the principal source of rust in this area is inoculum from overwintered local infections, (3) that the weather of December, January, February, and especially March is critical in determining spring renewal of the rust, and (4) that the level of rust intensity on April 1 is the principal factor determining its destructiveness from April till harvest in June, since the number of possible generations of rust increase is limited by time, even though the environment is constantly favorable, and the initial intensity of the rust April 1, the other factors being constantly favorable, will determine the final outcome of the disease.

FORECASTING SUGAR BEET DISEASES: -- The exceedingly destructive curly top disease of sugar beets is transmitted to beets by the beet leafhopper, which overwinters and breeds on certain weeds that are also sources of the curly top virus. The degree of damage from the disease in beets depends on the size of the overwintered leafhopper population and the earliness with which this population moves into the beet fields. The size of the leafhopper population, in turn, depends on the prevalence and abundance of weed hosts, and the rate of insect multiplication, while the spring weather conditions influence both the leafhopper multiplication rate and the time of their migration from weed hosts to crop fields.

Knowing these facts it becomes possible, by studying the weather and the behavior of the leafhoppers in their weed hosts, to forecast the time and intensity of infestation of the sugar beet crop, and this can be effectually done before beet-planting time. Warned by a forecast of a season of severe curly top, growers can avoid losses by planting only curly-top-resistant beet varieties or even planting substitute crops.

With another sugar beet disease, black root rot caused by Aphanomyces cochlioides, occurrence of the disease may be forecast before planting time by use of a greenhouse soil infection test (FINK, 1948). Previous to planting, soil samples from prospective beet fields are planted, in the greenhouse, with disinfected seed. After 30 days the percent of infected seedlings, which may range from 0-100%, is recorded, and FINK has shown that these records are very highly

correlated ($\underline{r}$ = +0.925) with crop loss in the field ranging from 0-95%. Other instances of measuring the pathogen content of soil, water, air, or wild host plants, and using this information in forecasting disease occurrence are discussed on pages 252-253.

OTHER CASES OF DISEASE FORECASTING: -- It has been pointed out that a knowledge of the tempo of disease development has a practical application in permitting the forecasting of disease destructiveness. In the case of alfalfa wilt the forecast may be projected into future years by using data such as those shown in Figure 7 (page 236), while in dealing with the sugar beet yellows disease (M. A. WATSON, D. J. WATSON, and HULL, 1946) a study of disease tempo makes it possible to forecast yields, which aids in planning beet sugar factory operations.

In Texas, EZEKIEL (1938) found a good correlation between May-July rainfall and the amount of Texas root rot subsequently developing in cotton. Over the extent of the area where it holds, this correlation gives the opportunity for forecasting cotton losses several months before harvest.

No account of plant disease forecasting would be complete without reference to the forecasting of timber decay, the most important hazard in forest yields, which stands out as an exemplary case of putting theory to work with results that are highly reliable and useful. This subject has been discussed on pages 250 and 251.

It should be clear from these examples that the prediction of plant disease outbreaks and losses is not guesswork. It is a useful application of the study of plant disease appraisal and epiphytology, with a record of reliability that compares very favorably with the admittedly justifiable forecasting of weather, crop yields, and other natural occurrences. It is equally clear that plant scientists have made only a bare beginning in developing this phase of their research, and that a great field of service to agriculture lies before us, awaiting cultivation.

Chapter XII

ECONOMIC ASPECTS OF PLANT DISEASE LOSSES

TYPES OF LOSS CAUSED BY PLANT DISEASE: -- KLEMM (1940) has suggested the useful distinctions between direct and indirect, actual and potential, and avoidable and unavoidable losses.

Direct losses result from a reduction in volume of production (quantitative) or in intrinsic value or acceptability of the harvest (qualitative). To the farmer, direct loss usually means a decrease in monetary return for his labor and investment, although, as will be seen later, he may be partially or fully compensated for direct loss by a higher price received per unit of produce or by a lowering in quality requirements such as often occurs when produce is scarce. In any event, the full effects of direct loss are felt by the consuming public, which bears the entire cost of the loss through increased prices or taxes used to compensate the farmer, yet receives less produce for the money spent and frequently must accept produce of inferior quality.

Indirect losses include the decreased purchasing power of the agricultural population and those dependent on it, together with the decreased activity, economical operation, and profits of those industries that are dependent on agriculture, such as grain elevators, mills, processing plants, railroads, banks, farm implement and agricultural chemical manufacturers, and others. Also to be included in indirect losses are the expense of replacing lacking produce by importation from regions outside those affected by crop disease, sometimes including the necessity of accepting less desirable substitute products.

Actual losses include the unredeemed value of decimated crops and all of the direct and indirect effects mentioned above. Even when disease has been partially or entirely averted by intervention of preventive measures, the cost of these measures, -- spraying, soil disinfestation, replanting, and others -- together with the cost of the research that devleops them and the educational programs that diffuse knowledge about them, must be added to the sum of actual losses.

Potential losses are those which would occur in the absence of preventive measures. Where economical disease control practices are possible, agriculture must choose the lesser of two evils, the actual loss due to the cost of control if less than the potential loss in the absence of control. With diseases that are restricted by regulation, the actual loss, the cost of quarantines and other regulatory measures, is usually less than the potential loss were the disease permitted to spread freely, but there have been cases in which a disease has been less costly than its regulatory restriction, i. e., in which actual loss exceeded potential loss.

The terms avoidable loss and unavoidable loss are self-explanatory. Many farmers, through ignorance or inertia, regard avoidable losses as unavoidable, and one of the leading problems in agricultural education is teaching farmers that most plant disease losses are partially if not entirely avoidable.

To KLEMM'S classification may be added the distinction between recognized and hidden losses. The extent to which a "normal" crop falls short of its potential yield is hidden loss and this may be very great, as will be seen later. Market requirements for agricultural produce give little attention to nutritional quality, provided the produce has purchaser-appeal. We are beginning to realize that many of our foodstuffs, regardless of their attractiveness, are deficient in needed minerals, vitamins, proteins, and other nutrients. To the extent that these nutritional deficiencies are expressions of disease, whether contagious or physiogenic, they must be regarded as hidden losses caused by disease.

Recognition and distinction of the several types of loss is useful in analyzing the economics of plant disease. In pointing out the agricultural significance of plant pests, we deal with the total actual losses, direct and indirect, avoidable and unavoidable, recognized and hidden. In describing the agricultural significance of plant protection, attention is focused on the potential losses, those that would occur in the absence of pest control. In calculating the cost of disease control in labor and money, we are concerned with the actual, avoidable, direct forms of loss. In agricultural research and propaganda for the support of research, the currently unavoidable losses are of greatest interest, in contrast to educational programs where the avoidable forms of loss are chiefly involved.

In reports on loss from plant diseases it is frequently impossible to tell what forms of loss are included, and discrepancies in the reports are partly due to differences in the forms of loss considered. Statistics on plant disease losses usually are limited to actual, direct, recognized, avoidable and unavoidable losses. In most cases they are further limited to quantitative losses, but not invariably so, particularly if sale value of the crop, which to some extent includes quality, is the basis of the report.

THE ECONOMIC CLASSIFICATION OF PLANT DISEASES: -- The German Plant Protection Service has classified diseases and insect pests into five groups according to the magnitude of their destructiveness (KLEMM, 1940). These are: (a) those which practically eliminate the culture of a given crop unless rigidly controlled, with average losses exceeding 20% of the crop, illustrated by the phloem necrosis of elm and potato wart; (b) those which are sporadic but wipe out crops during occasional years, as potato late blight and the cereal rusts, with average losses of 5 to 10%; (c) those which are only occasionally and locally important, such as potato scab, or white rust and downy mildew diseases of spinach, with average losses less than 5%; (d) those which are widespread but without an important yield-depressing effect, as the cereal smuts and many of the leaf spot diseases of trees and herbaceous plants, causing about 1% loss on the average; and (e) those diseases which, on the average, have little or no agricultural significance, as ergot of grains and several of the needle rust diseases of conifers. Through ignorance of losses, diseases of considerable importance are sometimes placed in the last of these classes, as KLEMM did with wheat foot and root rots, which are now known to be major diseases. The indicated amounts of average loss are only approximate, with higher losses occurring in individual cases.

Alternatively, diseases may be classified in a qualitative fashion, as YACHEVSKI (1929) has done. Modifying his scheme, we may recognize nine classes: (a) diseases seriously affecting the normal life of plants, frequently killing them, as in the wilt diseases and damping-off; (b) diseases that destroy the commercial parts of the plant, as the smuts of small grains and cotton boll rots; (c) diseases that destroy the reproductive organs, which may or may not coincide with cases under "(b)"; (d) diseases that stunt or retard the growth or weaken the plant without killing it, as is true of many virus diseases; (e) diseases that indirectly injure the commercial product by attacking other plant organs, as the foliage diseases of root, fruit, nut, and seed crops: (f) diseases that confer poisonous or other undesired properties on the product, as ergot of grains or scab of barley; (g) diseases that attack harvested products in storage, commerce, or home; (h) diseases that injure the attractiveness or aesthetic qualities of the product, as peach freckle, apple fly speck, and blemishes of ornamental plants; and (i) mixed and intermediate types, with combined features of two or more of the foregoing classes.

In evaluating the actual or potential destructiveness of a disease, it is necessary to characterize it both quantitatively and qualitatively and to seek to avoid the pitfalls that lie in its incorrect classification.

CONCEPT OF A "NORMAL CROP": -- Theoretically, the severity of disease is the extent to which the diseased plant falls short of its ideal development. Such an ideal plant probably never exists. An instructive exercise is to attempt to find a single "perfect" mature leaf in nature.

While we may never be able to know the absolute maximum yields that might be obtained under ideal conditions, with total freedom from disease, we approach to a knowledge of this with every improvement in the appraisal of losses. Actual yield, $\underline{y}$ = theoretical yield, $\underline{Y}$, minus loss, $\underline{l}$. Knowing $\underline{y}$ and $\underline{l}$, $\underline{Y}$ can be calculated, and the accuracy of determination of theoretical yield depends only on the accuracy with which we determine $\underline{l}$, which is the task of loss appraisal.

Present knowledge, imperfect though it is, gives us reason to believe that under most agricultural conditions theoretical yields are far beyond actual yields of what are considered "normal" crops, and that economically attainable yields are much greater than is commonly believed. NEIL STEVENS (1935) has stated that there is always a 25% loss from fruit rots alone in "normal" cranberry crops. What had been considered good "normal" crops of alfalfa have been increased by 50% by a single application of an insecticide (PEPPER, 1947) and it is probable that control of leaf diseases would step up alfalfa yields another 50%.

WHEELER M^C^MILLEN, editor of "Farm Journal", has been conducting a most interesting contest aimed at production of 300 bushels of corn on a single corn-belt acre by providing the crop with as nearly ideal conditions as possible. Although the average corn yields in the United States (1935-1944) ranged from 10 bushels per acre in Florida to a maximum of 47 bushels in Iowa, M^C^MILLEN'S cooperators have succeeded in harvesting as much as 200 bushels per acre even in a season of unfavorable weather. While it can be justly argued that the point of diminishing returns and of uneconomic expense may be reached long before maximum yields are secured, especially with heavy applications of fertilizer and water, there still remains a wide margin between actual, so-called "normal" yields and <u>economically attainable</u> yields from pest-free crops.

Usually this margin of potential profit and the defects of the "normal" crop are wholly unrecognized by farmers and not infrequently even by agricultural scientists. It would be difficult for an Aroostook County potato grower, surveying a better-than-average crop, to recognize that even if the crop were perfect in every other respect it still would be only 87% of a truly healthy crop, since the X-virus, invariably present in all his plants, exacts a regular toll of 13% of potential

yield. McMILLEN'S contest has shown that not all farmers are impervious to the challenge to strive forward toward maximum yields, yet to the majority of farmers a crop yielding 10% more than average for the neighborhood is entirely satisfactory, and a suggestion that it falls seriously short of feasible yields would be met with disbelief if not ridicule.

The term "normal yield" is used with different meanings from one reporter or country to another. In the U. S. Department of Agriculture (VALGREN, 1922) the "normal yield" is that which occurs in good years over extended areas, and a crop exceeding this by 10% is regarded as a perfect undamaged crop for the area. In Germany (KLEMM, 1940), the "normal yield" is the theoretical yield for an entirely normal year, assuming average injury from pests, and in practice it corresponds to a 6- to 8-year average yield. This, which would better be termed "average yield", is somewhat more realistic than the American standard, and avoids the absurdity of reports indicating that particularly well-favored crops have produced somewhat more than 100% of production of the "perfect crop", as well as the false implication that the utmost that can be achieved by a farmer is the increase in yield by a paltry 10% more than the local average in good years.

It seems most logical to avoid the deceptive and nonuniform use of the term "normal yield", restricting usage to the measurable "average yield", and limiting use of the concept of theoretical or perfect yield to experiments aimed at revealing it and to education of growers toward an application of feasible achievements in increasing yields well beyond those commonly called "good" or "normal".

EFFECTS OF PLANT DISEASE ON THE INDIVIDUAL GROWER: -- Plant disease presents a triple threat to the farmer. It may injure him as an individual producer in competition with other farmers, as a member of the national farming profession, and as a consumer of those agricultural commodities that he must purchase.

Were the losses from plant diseases equally prorated among all farmers, we could disregard individual differences, but they are not. Great variations in yields and losses may occur on adjacent farms in the same season. For those who are not close to the land there is comfort in the statistic that the average wheat acre in the United States produced 18 bushels of $2.00 wheat in 1948. How little this means in human values to the farmer who harvested 30 bushels per acre or his neighbor who harvested 5! Some diseases, such as root rot, are like that. Average national losses from disease, serious though they are, have but a small fraction of the social significance of the multitudes of individual catastrophes that are lost sight of in the national or state averages.

From the national standpoint, decreased yield is usually associated with increased prices, as discussed below, but this has no significance to the individual farmer whose decimated crops are too small a fraction of national production to have any effect on the price received. Conversely, the farmer who avoids disease losses by adequate attention to preventive measures, profits out of all proportion to variations in national production.

The same principle extends to groups of farmers whose combined production has little effect on national price, and who suffer losses from regional disease outbreaks. NEIL STEVENS (1935) illustrates this in an outbreak of cranberry false blossom (virus) that caused a local loss of $2,000,000 in New Jersey, without greatly affecting the national price of the crop. There was some price benefit to the national cranberry industry from the reduced supply, but far too little to compensate for the tragic loss to the New Jersey growers.

National losses expressed in dollars may entirely obscure the socio-economic effects of those losses on the farmers concerned. A loss of 0.5% of the national wheat crop would equal, in dollar value, a total loss to the cranberry industry; yet the former would be undetectable to the wheat farmers while the latter would be ruinous to a small but sociologically significant population whose livelihood depends on the cranberry crop.

EFFECTS OF FLUCTUATIONS IN ANNUAL YIELDS: -- It is an elementary principle in economics that fluctuation in income from month to month or year to year works hardships even though the total amount received over a long period is adequate. This principle is well recognized in agriculture. Many farmers can survive one year of crop failure, some can survive too, but very few could remain on the land after three years of failure, which fact would not be altered by the knowledge that total income in ten years, if divided into equal annual increments, would be adequate. In Argentina there is a wheat variety which has a high long-time record for production but with great extremes of high and low yields from year to year. It is called a "wheat for capitalists" and is not recommended to farmers, who are urged to grow other varieties that do not produce as much grain over a long period, but do produce fairly consistently, year in and year out.

Regularity in yield is as important to agricultural welfare as volume of yield and "fluctuations

in yield can cause as much embarrassment as unbalanced acreages" (WALLACE). Since plant disease can markedly affect yields, it is instructive to see how this relates to yield fluctuations. Diseases differ in their effects on dependability of yields and, as NEIL STEVENS (1939) points out, "other things being equal, including average loss, that disease is most important which fluctuates most." Regularity in production has a beneficial stabilizing effect on farm prices.

There are some diseases, that, like poverty and taxes, are always with us, always injuring the crop to about the same extent. Among these is wood decay. Others are relatively constant but occasionally they become exceptionally severe or mild, as wilts and other soil-borne diseases. Still others attack with devasting force one year and are practically absent another, as potato late blight and cereal stem rust. Other factors being equal, the latter would be regarded as most destructive.

McCALLAN (1946) has tabulated the ranges in loss percent for 36 major crop diseases during a ten-year period. Some of these show great variation between maximum and minimum, as the losses from corn root, stalk, and ear rots (3.8-16.1%), cotton seedling blight and boll rots (0.2-11.6%), apple scab (2.8-14.1%), wheat stem rust (trace-23.0%), pear blight (1.6-13.6%), potato late blight (0.8-12.8%), and sweet corn wilt (trace-13.1%), while with other diseases the losses vary little between their extremes, as is true of cotton wilt (2.2-4.8%), cotton root rot (2.3-5.0%), corn smut (2.0-4.6%), oat smut (2.5-4.7%), and potato rhizoctonia (1.5-3.5%), scab (1.5-2.6%), leafroll (1.2-3.5%), and mosaic (1.4-2.6%). Other diseases that are responsible for great annual variations in yield are sweet potato surface rot (HARTER and WEIMER, 1919), tomato anthracnose (McNEW, 1943j), and storage and market disease of perishable produce generally (LINK and GARDNER, 1919).

HARTLEY and RATHBUN-GRAVATT (1937) have contributed a valuable discussion of disease damage in relation to host vigor. They have emphasized a point that is not often recognized by agriculturists, namely that all plant diseases may be divided into three classes: (a) those which mainly attack devitalized, weak plants; (b) those found principally on the most vigorous plants; and (c) those that are relatively indiscriminate, attacking vigorous and weak plants alike. In general, the diseases caused by rust fungi and other obligate parasites, as well as those caused by downy mildew fungi and bacteria, belong to the second class, while wilts, roots rots, cankers, and wood decays are usually of the first type.

These two classes of disease are quite contrary in relation to effect on yield fluctuations. A disease that is found principally on weakened plants accentuates that weakness, exaggerating yield depression, deepening the valley in the yield curve between yield peaks from more vigorous and disease-free crops. A disease that attacks only the more vigorous plants lowers the peaks without deepening the valleys, thus reducing yield fluctuations. From this standpoint alone cereal rusts and potato late blight might be regarded as beneficial. These relationships may be expressed as a coefficient of correlation, r, between disease loss and potential yield in the absence of disease, over a period of years. If r is negative, the disease increases the annual yield variation, and if r is positive the disease is associated with reduced yield fluctuation. Thus for cotton wilt, r = -.36, increasing variability, while with potato late blight r = +.82. In the latter case complete control of the disease would increase the yield variability, and late blight may be regarded as a stabilizing factor in potato production under the conditions of the observations.

This apparently beneficial effect of diseases with positive r values does not apply when the diseases attack with epiphytotic force, causing heavy losses over extensive areas, i. e., when the disease is more important than weather fluctuations or other factors contributing to crop vigor.

When two diseases attack a crop simultaneously, the second disease may add to the effect of the first in increasing or decreasing yield variability, or the effect of one disease may neutralize the effect of the other, with decreased net effect in fluctuations of yield. HARTLEY and RATHBUN-GRAVATT mention the antagonistic effect of potato tipburn and late blight in reducing the effects of one another as regards yield variability.

CUMULATIVE EFFECT OF SOIL-, SEED-, AND TUBER-BORNE DISEASES: -- When a potato plant becomes infected by a virus disease, the loss includes not only the reduced yield during the season of infection, but also the series of losses that occur in succeeding years as the virus is perpetuated in the tuber progenies and spread from these, each year, to neighboring healthy plants. SCOTT (1941) has shown that severe potato mosaic increases in seedstocks two- to three-fold and leafroll four-fold from one year to the next. Mild mosaic, according to K. M. SMITH (1933) reduces yields of potatoes 10- to 30 % the first year, with no further loss increase the second and third years, but rugose mosaic, causing 30 to 65% loss the first year, makes potato strains unproductive in two to three years. When potato seedstocks are not selected for freedom from disease, but are replanted year after year, the cumulative increase in disease and decrease in yield are illustrated in the data of GRAM (1923). In one of his tests with the leafroll

disease, where tubers were replanted each year for five years, the disease incidence rose from 18 to 96%, accompanied by a decrease in yield, in centners/hectare, from 18.2 the first year to 2.2 the fifth.

Analogous cumulative losses are seen in other virus diseases that are transmitted by vegetative propagation, such as sugar cane mosaic, and in diseases that are carried by the true seed, as with the cereal smuts. With soil-borne diseases, such as root rot, a comparable cumulative loss effect is observed.

SOME ASPECTS OF LOSS IN PERENNIAL CROPS: -- Each season a perennial plant must accumulate reserves for next year's production, as well as produce a crop during the current year. Disease in any given year may not only reduce the production of that year, but may also have carryover effects, reducing the crops of succeeding years. Several injurious effects are involved, -- prevention of food storage, killing of branches and formation of cankers or lesions that cripple the plant for years to come, and the building up of a reservoir of disease inoculum which increases the hazard of exposure with each succeeding year. Defoliation of fruit trees by insects or diseases commonly has an injurious effect on the crop of the following year, though its effect on the present year's crop may hardly be detected. This is well illustrated by the cherry leaf spot disease. If defoliation is repeated for several years, trees commonly cannot survive.

A related effect that disturbs production by contributing to variability in annual yields of perennials, especially fruit and nut trees, is seen in cases in which a bumper crop one year is followed by a very poor crop the following year. This may not be associated with contagious disease; in fact, a disease that results in some fruit thinning during the bumper crop year may be beneficial in contributing to more constant yields.

RELATION OF LOWERED QUALITY TO MARKET QUALITY REQUIREMENTS: -- All plant diseases may be divided into those which reduce yields without affecting the quality of the harvested crop, such as loose smut of wheat except in growing the crop for seed production; those affecting both yields and quality, including the majority of diseases; and those that impair quality of the harvest without affecting yield, as in the case of diseases that only blemish fruits. In the first case, loss is measured purely in terms of volume of production, but in the latter two cases the amount of loss is related to market acceptability of the crop. Although losses due to lowered quality of produce are not often included in loss estimates, nevertheless they frequently represent a large or major share of all loss due to a disease.

Market quality requirements may be difficult to understand. Often they relate to psychological peculiarities or the sales-conditioning of the purchaser, as seen in such nutritionally unsound preferences as those for white bread and blanched vegetables. Moreover, market requirements vary from one location, season, or part of a season to another, and with the intended use of the product.

There is no consistent relation, that might benefit the grower of a disease-injured crop, between supply and quality requirements. If the supply is short there may be some relaxation in quality requirements, and every housewife is familiar with occasions when, for example, apples are scarce in the market, and despite the high price most of the fruit offered for sale is scabbed or blotchy. If this were invariably the case the grower would be somewhat compensated by a normally good price for his inferior produce, but there are many cases in which market practice works in the opposite fashion. For cranberries, NEIL STEVENS (1935) has pointed out that low quality in the first berries marketed may set a low price that affects all berries sold during the season, and the same thing has been observed by P. A. MILLER and BARRETT (1931) for cantaloupes. A striking case of this kind was reported for celery by NELSON (1939), who found that in the worst disease year in two decades, "prices paid to growers reached the lowest level in many years, and a more stagnant condition of the markets had probably not occurred previously ....Large quantities of celery were dumped on the market at prices which lowered the levels established for celery of good quality."

Low quality of produce may divert the buyer to other products, making the poor produce a drug on the market, and, in contrast, abundance with high quality may elevate the price by inducing speculators to buy the superior crop for storage and later sale.

Quality requirements depend on the purpose for which a product is to be used. A product that is inferior for one use may be satisfactory for another, though usually the value received drops as the product is rejected from its first intended use. The quality requirements for potatoes sold as seed tubers are higher than those for table stock, and potatoes rejected for seed might still be accepted, although at a somewhat lower price, for table use. Governmental interference with prices throws another uncertainty into this picture of market requirements, and

there have been cases in which culinary potatoes of poorer quality have actually sold in the same market at a higher price, inflated by price support, than that charged for the better quality seed potatoes, which have then been bought by housewives for table use.

The effect of the downy mildew disease on onions varies with the use intended for the crop, being greatest if the crop is grown for greens, less if it is grown for bulbs, and least if it is grown for seed (YARWOOD, 1943). Wood decay exemplifies the same point (HEPTING and HEDGCOCK, 1937; MEINECKE, 1929). As the cull percent in a given stand increases, the volume of marketed timber decreases but its quality is higher. The market has very high quality requirements for timber to be used for railroad ties and much lower requirements for pulpwood. In the first case the effect of decay is chiefly in reducing quantity of the crop, and in the second, it is expressed as lower price.

The reduction of loss in marketing practice depends on selecting a compromise that may involve some loss in volume and some loss in price, but yet brings in the greatest possible return. This has practical application in the case of wood decay, mentioned above, and in the moderate artificial thinning of fruit, where increase in quality and price more than offsets decrease in volume of production.

Customarily the price for an agricultural commodity is highest when the crop first comes onto the market and steadily decreases as the season progresses and the volume of produce offered for sale increases. A disease which reduces the late-season harvest causes a financial loss that is much less than a disease causing an equal volume of loss early in the season. It may be profitable to spray such a crop as tomatoes to save the early fruits, yet not profitable to spray later to protect an equal volume of fruits that, if harvested, would reach the market at a time when the seasonal price has dropped to a low level. This point is commonly overlooked or lost sight of in statistics that report losses in bushels without indicating whether those bushels were of high-priced early season produce, or of late-season, low-value yields.

ABANDONMENT OF CROPS; FARM FAILURES: -- The most unfortunate victims of plant disease are two classes remotely removed from one another socially, the farmer to whom loss means ruin, and the lower fringes of the nonagricultural population to whom high prices and food shortages mean malnutrition if not starvation. Between is the great bulk of population to whom shortages in agricultural production mean only a little privation, a change in habits, or a tightening of the belt. We can say nothing here of those millions to whom a shortage in supply means suffering, -- their plight is a problem involving all agriculture, political economy, and the social structure of our civilization. Here we must limit ourselves to the men, women, and children at the other pole, -- those to whom a disastrous outbreak of plant disease means the end of their livelihood.

The economic history of plant pathology, though never yet assembled and existing only in scattered items, is a tragic chronology of disaster after disaster which have scourged the land, wiping out the livelihood of countless families, communities, and whole agricultural sections, destroying enterprises on which hopeful farmers had staked their lives and all their resources.

NEIL STEVENS (1934b, 1938) has presented a formidable list of agricultural projects known to have failed as a result of plant diseases. Some of these have resulted in virtual elimination of industries on which more or less extensive areas have depended, as the virtual collapse of the Louisiana sugarcane industry when it was successively crippled by red rot, root rot, and mosaic (RANDS and DOPP, 1938), the fate of the sugar beet industry in the intermountain region, throttled by the curly top disease (CARSNER, 1944) and the elimination, by rust, of the coffee growing in Ceylon in the 1880's, and the culture of Coffea arabica in Java (MORSTATT, 1937). Calamities such as these eliminated the livelihood of large populations, closed mills and factories, transformed prosperous communities into ghost towns.

Less spectacular, though no less ruinous to many individual farmers and those dependent on farming, have been the many other instances in which disease has struck locally or on scattered farms, eliminating the culture of once profitable crops, forcing countless individual farm families off the land or into other, less attractive agricultural pursuits. The many plant diseases that have acted in this fashion, mentioned by STEVENS and others, include banana wilt, flax wilt and rust, sweet potato surface rot, wheat stem and leaf rusts, potato and tomato late blight, alfalfa bacterial wilt, rusts of asparagus and snapdragon, fusarium wilts of watermelon, cotton, and other crops, Granville wilt of tobacco, diseases of celery, gooseberry-powdery mildew in Europe.

In these cases the destruction of crop culture has not always been permanent; sooner or later plant scientists have found means of controlling many of these diseases or have developed profitable substitute crops. Yet, during the period of reorganization of farming, untold suffering has been undergone by the stricken farm populations.

We have no yardstick for measuring this kind of loss. Disastrous total loss for a minority of

farmers is completely overlooked in national statistics. The introduction of substitute crops to some extent compensates for the damage, but still leaves serious injury involved in adjustment to new ways of agriculture, replacement of equipment suitable only for the old crop, and inexperience in culture of the new one. As the cost of war or famine in human values can never be calculated, neither can the cost of the countless cases of individual total loss, the agricultural failures that lead to abandonment of crops and of farms. However closely we may attempt to arrive at estimates of the cost of plant disease, our figures will always fall short of the true cost by a broad margin of intangible suffering that cannot be measured in dollars.

EFFECT OF PLANT DISEASES ON THE USE AND VALUE OF LAND: -- Cropping practices have evolved through a process of trial and error by farmers. Each area grows the crops that practical experience has shown thrive best in the area, and farmers have gradually come to realize that certain crops will not succeed in given areas. It is often understood that the restriction of crops is due to soil, water, or temperature characteristics of an area, but growers and even agricultural specialists frequently overlook, or do not know that the absence of culture of given crops in some areas is due to the high disease hazard, which led to discouraging results in early, exploratory trials to determine what crops might be profitably grown in those localities. A climate very favorable for powdery mildew and leaf rust, rather than any unfavorable direct environmental influence, is undoubtedly the chief reason limiting the culture of wheat and barley in the cotton belt of the United States, just as Texas root rot, whether recognized or not, is the principal factor that has led to culture of cereals, rather than to more profitable cotton, alfalfa, or horticultural crops, in many infested areas of the Southwest.

Insofar as disease hazards dictate that certain crops may not be grown on land otherwise adapted to their culture, disease is causing a loss which may be very great if the land is not well suited to substitute crops. Uneven sandy lands are suitable for watermelon culture but for little else, and, in the past, when the land became infested with the deadly wilt fungus it had to be abandoned for melon culture and reverted to scrub oak of little value. Crucifers, particularly cabbage, have special soil requirements unlike those of most other crops, and if the land becomes contaminated with the club root organism, no equally valuable crop may be found to replace the crucifers. The same can be said for alfalfa and its wilt disease, sugar beets and the beet nematode, and numerous other cases, of which NEIL STEVENS (1934b) gives a long list.

Where the best adapted crops cannot be grown because of the disease hazard, the land declines in capital value, as was the case of North Carolina tobacco land until scientists found a means of controlling the Granville wilt disease. Acting in the opposite fashion, the development of means for controlling a disease may make it possible to grow a sufficient quantity of the crop to meet market demands on a smaller acreage. This releases land for other purposes and may or may not reduce the capital value of the surplus land.

Whatever the effect of disease, or its control, on land values, it is clear that in many cases the disease hazard is as important a characteristic of land as its fertility, water supply, and topography. Many Texas farmers in root rot areas have learned this fact the hard way, and much hardship and error could be avoided if land appraisal would regularly take into consideration the disease potential. From our point of view we must regard this effect of disease on land usage and values as an indirect, but nevertheless significant, aspect of disease loss.

EFFECT OF PLANT DISEASES FROM THE NATIONAL VIEWPOINT: -- When we consider t[he] effect of plant diseases purely from the point of view of total national production and national prices, at first sight it appears that diseases are beneficial to the farmer, since reduced production is usually more than offset by increased prices, a large crop actually being worth fewer dollars than a smaller one. This is brought out by statistical demand curves that relate producti[on] to price.

In a comprehensive study of demand made by H. S. SCHULTZ (1938), it was found that for 1[...] major crops all but one had inelastic demand curves, i.e., as supply increased the price decreased in greater proportion. The exception was rye, the price of which was very artificial during t[he] period of study (1915-1929) owing, perhaps, to the national prohibition law and other regulations of the distilling industry. In an earlier study period, (1875-1914) rye also had an inelastic dema[nd] curve.

With corn, a 0.5% decrease in production was associated with a 1% increase in price. With cotton, a 1% increase in supply depressed the price 1.4%. A 1% increase in supply of wheat reduced the price 2%. Similar trends were observed for sugar, hay, potatoes, oats, and barley, in which 1% increase in production resulted in price decreases of 2.5-3.3%, 2.3%, 3.3%, 1.67% and 2.56%, respectively, a bigger crop of any of these bringing the farmer a smaller return. It follows that any agricultural practice that contributes to increased production may reduce the ca[...]

value of the crop. As HENRY WALLACE put it: "Science has made two blades of grass grow where there was only one before, only to find the second blade depressing the price of both."

Are we to conclude that agricultural science is harmful insofar as it increases production, thereby reducing farm income? If we do, we must sanction WALLACE'S policy of destroying crops and little pigs, we must close our eyes to the millions of nonagricultural consumers to whom decreased production means higher prices that buy poorer quality. and we must close our hearts to the many more millions of people throughout the world to whom anything short of maximum production means malnutrition or death by slow starvation.

Agropolitical assertions to the contrary, there never has and probably never can be overproduction from the sociological and humanitarian point of view. So-called overproduction is simply economic and social indigestion, brought about by artificial restrictions of trade, price manipulation that prevents the needy from purchasing, and economic isolationism. There can never be overproduction so long as there remain, anywhere in the world, multitudes who never know what it is to be properly fed and who die in middle life from the weaknesses of malnutrition. If the humanitarian viewpoint is incompatible with the economic one, in the interests of Christianity and world peace it is the latter, not the former, that must yield.

We have momentarily assumed, as a general principle, that, because of the inelasticity of statistical demand curves of a few leading farm crops, the farmer gains when production is curtailed. Is this assumption valid? There are so many important exceptions to the operation of the demand law and its effects that we may very well be justified in concluding that today the exceptions are the rule. The general applicability of the demand law, if it is to benefit farmers, includes the requirements that decreased production most frequently is more than offset by increased prices, that these benefit the majority of farmers, that the minority of farmers who lose rather than gain by decreased production can be disregarded in the national picture, that the law derived from statistics of 1915-1929 applies today, and that the law applies to crops generally. None of these assumptions is entirely valid.

The practice of farm price supports, which seems to be here to stay, is a repeal of the demand law; it fixes prices regardless of production, and under it the farmers' income increases directly as their production increases.

With decreasing production there is a point beyond which further decrease, even under ideal operation of the demand law, reduces rather than increases income. Simple calculation shows that this is the point of 50% yield reduction. Obviously, if production is reduced to 10% of normal, the price will not increase more than 1000% to guarantee an equal money return. As production approaches zero the price would need to approach infinity in order to sustain farm income, and long before this point is reached the market, at such prices, would vanish. It is only in the minor fluctuations around average yields that the demand law could be expected to operate.

Crop production is so beset by hazards that on the individual farms, which, combined, produce the nation's crops, the fluctuations from normal are great, with losses and gains greater than 50% not uncommon. There is little comfort for a farmer to know that decreased national production has raised the price of a crop a few pennies when his own farm was one of those on which serious loss depressed national production and increased prices at his expense and to the main advantage of other farmers. The suffering minority cannot be disregarded. Most of history has been written by dissatisfied minorities, not by contented majorities. The richest fruits of agricultural science are its benefits to the least productive farms, where hazards are greatest and improvements are most telling, and, even if it could be conclusively shown that science has resulted in nominal price decreases through increased production, this would be a minor loss to farmers themselves, considered as a multitude of individuals and as an impersonal class, compared to the major socioeconomic gain. All insurance exists on the same basis: from the total viewpoint insurance is a loss, since part of its cost is never returned to the policy holders, yet who can deny that the net results of insurance, in its protection of the unfortunate minority, far outweighs the cost of supporting the insurance industry?

Discussions of production-price relationships are based on demand law studies involving use of data of past decades. During these earlier periods, prices were fairly free to respond to production levels, as must be the case if the demand law is to function. Today this is no longer true. Price supports and manipulation by governmental decree, independent of production, with dumping of "excess" produce, huge government purchases for donation to foreign peoples, the increasing importance of the world market, inflation of production costs, long term crop storage activities, a ponderous and inequitable tax structure, and revaluation of money at home and abroad, -- these are among the many factors that interfere with the automatic balancing of production and price, and they lead to the frequent instances in which domestic production appears to bear no consistent relation to price. The demand law cannot explain the rise in wheat prices from 56 cents per bushel in 1938 to more than $2.00 in 1948, while production was also rising, nor can

this be explained by inflation alone. Between 1931 and 1932 United States wheat production fell by nearly 200,000,000 bushels, yet the price, instead of rising, actually dropped.

Finally, the demand law is based on ten leading crops that must be purchased with little regard to quality. Plant diseases that reduce production commonly reduce quality at the same time, and with the perishable crops, consumption of which may be replaced by others, the lowered quality often reduces the demand and price far beyond any gain due to the reduced volume. If beans are scarce and rusty, the housewife will buy peas or corn; if citrus fruits are low in quality, she knows that the plentiful tomato juice has comparable food value; and in cases like these the scarce and less desirable produce, instead of commanding a compensating higher price, may have no price at all.

The moral of this discussion is clear and simple: the agriculturist who takes comfort in the thought that reduced production will bring its reward in higher prices is living in a world of unreality. Even from shortsighted and selfish restriction of interest to the farming class, there is little to gain and much to lose from hazards that reduce production. Crop losses do not create value; frequently they depress it. The prosperity of the farmer, as an individual and as a class, can only increase with more efficient methods of production and with increasing control over the hazards of production.

SECULAR PRICE EFFECTS OF NEW DISEASES: -- Now and then, in the history of agriculture, a new disease of devastating potency assails a crop, drastically curtailing its production. The effect of this on prices follows a standard pattern.

When the disease first appears, its inroads on production lead to scarcities that, to greater or less extent, may elevate the price of the crop attacked. As the price rises beyond that of competitive products, more and more consumers introduce themselves to substitute products and more and more growers turn to the production of these substitutes. Gradually the market value of the disease-stricken crop declines, as demand for it falls. This results in a situation in which the demand law has completely ceased to function and the loss in volume is multiplied by the loss in market value. This course of events may be considered as the secular effect of disease on price.

The fate of the American chestnut illustrates the secular effect. When the blight disease (<u>Endothia parasitica</u>) began its deadly course, wiping out the chestnut, there was a mad scramble for the highly prized timber, and the prices of tannin and nuts reflected the growing scarcity of supply. But as the years passed, other woods gained the former popularity of chestnut, other sources of tannin were found, and the taste for chestnuts waned with growing acceptance of other nuts, until the combined effects of lowered volume and reduced demand and price relegated the chestnut to a position of minor importance. Outside the field of agriculture, the decline in the whale fisheries, together with a decline in the demand for its products, illustrates the general application of the secular law.

LOSS ESTIMATES IN DOLLARS VERSUS THOSE IN PRODUCTION UNITS: -- For many years there has been disagreement whether crop losses should be expressed only in terms of lost bushels, bales, barrels, and tons, or whether it is permissible to translate these into dollars or other types of currency.

The antagonists of dollar estimates, a minority who include the succession of editors of the <u>Plant Disease Reporter</u> (Anon., 1918-1936), HAENSELER (1944), H. S. SMITH <u>et al</u>. (1933), and <u>WEISS (1940)</u>, raise as their principal objection the opinion that it is unwise to multiply the number of lost production units by the prevailing price for those units that are harvested, since, if the lost units had been offered on the market the volume of production would have been increased, which, according to the demand law, would have reduced the price per unit. Loss estimates in dollars are described as "unsound", "too complex", "too theoretical", "not needed to justify support", "leading to exaggeration", "meaningless", and even "fantastic".

These objections, whatever the adjectives employed, are valid if, and to the extent that, the demand law is the principal factor that would have altered the price had the production units not been lost. We have seen that the demand law, which once applied imperfectly to a few staple crops, now appears to be the exception rather than the rule. Since most crop loss statistics are used in relation to agriculture, the basing of an argument on the demand law implies acceptance of that law with all its implications, one of which is that, so far as the farmer is concerned, there is no such thing as loss from non-catastrophic production hazards, -- every crop loss is that much gain financially.

Another argument frequently heard is that a damaged, smaller crop costs less to harvest than a larger, healthy one, which decreases the dollar loss. The cost of harvesting is only one of many costs in producing a crop. Frequently, as in combining small grains, it costs just as much to cut and thresh the smaller crop as the larger one. Finally there is an error of logic in deduct-

ing non-incurred harvesting costs from estimates of lost profits. In the case of a 10% crop reduction, it must be assumed that all costs of production are reduced by 10% if the amount of profit is to bear a constant relation to the amount of crop grown and sold. Savings in harvesting cost are not offsets of the 10% loss; on the contrary, all costs of production, including harvesting, must be decreased by 10% if the loss is not to be greater than 10%. Inevitably some of these production costs cannot be saved, and as a result a 10% field loss regularly results in more, sometimes much more, than 10% loss in profit.

For a number of reasons the translation of loss statistics into dollars is not only justified, but actually gives a more accurate conception of loss than number or percent of production units.

Chief among these reasons is the fact that the loss from disease is often expressed as reduced quality, commanding lower prices, which may represent as much as or more loss than reduction in the number of production units. The only tangible way that the quality loss can be included in the over-all loss estimate is to list the loss in terms of market value, in dollars. As one of many examples that might be cited, McMURTREY (1928) showed that tobacco, infected with mosaic one month after transplanting, suffered a reduction of 24% in acre yield, but the quality was so reduced that the tobacco sold at a loss of 40% per 100 pounds, which combined gave a total dollar loss per acre of 54.5%. In this case less than half of the true loss was reflected in the expression of loss in production units.

In CRAIGIE'S (1944) excellent analysis of losses of wheat from stem rust in Canada, he expresses the loss in dollars with the explanation: "It is realized that.....an increased production would have probably lowered the price of wheat, but any fall in the price of wheat as a result of higher production would have been largely offset by a fall in price due to the loss of grade resulting from damage by rust".

Loss expressed in production units usually includes only those forms of loss that occur up to harvest time. Yet many plant diseases continue to exact their toll through storage, transport, and marketing. It would be possible to extend loss estimates in production units to include the post-harvest shrinkage of the crop, but in actual practice, all of the loss, including such items as extra refrigeration costs, culling expense, and insurance indemnities for spoiled produce, could most feasibly and accurately be summarized in dollars.

Because of these considerations it seems equitable and more correct to express national losses in terms of dollars, but this is even more true when dealing with losses on a local scale, where the amount of loss is not sufficient to alter the market price. In many disease control tests, where the cost of control measures is an important production item, it is essential to determine whether the economics of disease control are in favor of the grower. Control is measured in dollars, and, to obtain realistic and useful results, the production gain, which is the converse of disease loss, must be measured in the same terms, giving a net value in dollars for or against the economics of disease control.

The besetting evil of most plant disease loss estimates has been that they have seriously understated the damage. In an effort to be conservative, plant pathologists have been led to as great errors in understatement as they have feared in overstatement, forgetting that a body can lose equilibrium and fall over as easily from leaning backward as from leaning forward. The imagined error in the assumption that loss is compensated by increased unit value has far less significance than the real losses that can best be measured in dollars. There is certainly as much guesswork in scaling down losses because of assumed price increases as there is in translating percent loss into market price, and it is encouraging to find such leaders of plant disease science as HORSFALL, McNEW, VALLEAU, MORSTATT, and KLEMM reporting losses realistically in dollars and marks.

Finally, the writer cannot agree with HAENSELER (1944) that loss estimates in money are not needed to justify support for plant disease control activities. Millions of bushels of wheat or corn, more or less, mean little to the layman who controls the purse strings, but he is impressed with millions of dollars. Proposed agricultural activities are measured in dollars and their justification must be in the same terms if their real significance is to be grasped.

EFFECT OF PLANT DISEASE LOSSES ON THE CONSUMER AND SOCIETY: -- The consumer has a greater stake in crop loss prevention than does the farmer. Whatever the losses in agriculture, it is the consumer who must absorb them in higher prices, lower quality, and taxes to permit the farmer to operate despite agricultural hazards.

The consumer's stake is all the greater because the unit value of produce, when it reaches the consumer, is much higher than at the farm. "The consumer's apple is the producer's apple plus the cost of picking, packing, shipping, storage, and handling, as well as sales costs and profits" (NEIL STEVENS). A farm loss, measured in pennies per bushel, becomes a consumer's loss measured in pennies per pound or dollars per bushel.

The farmer's loss, which may be offset to some extent by higher prices or subsidies, involves only the hazards that exist up to harvest time. The consumer's loss includes these plus all the forms of loss that occur between harvest and the dinner table, and these post-harvest losses may be relatively much greater than losses on the farm. SHEAR (1918) has emphasized that "few people, even pathologists, realize what enormous quantities of fruits and vegetables are lost through disease, decay, and other preventable causes between the producer and the consumer". He, as well as LINK and GARDNER (1919), cite many cases of the enormous amounts of produce that are lost from disease during the marketing process. These included condemnation of 19,000,000 pounds of fruits and vegetables in New York during one year, and railroad indemnities exceeding 2.6 million dollars for spoilage of perishables during a year.

It is not uncommon for 25 to 50% of perishable produce to be lost between farm and home. The most shocking part of this is the fact that these huge losses are regarded by the marketer as "normal shrinkage". Culling, resorting, and repacking occur again and again as the produce moves forward to the home, each step being marked by additional loss, and this is considered "part of the game", not as preventable waste. The consumer has been conditioned to pay the bill.

To the direct losses that are reflected in the cull piles behind warehouse and market and in the family garbage container, must be added the many indirect forms of loss that also are chargeable to the customer, as hidden taxes. These include the added costs imposed by spoilage on the food packing industry, the transportation agencies, and the marketer, transit insurance costs, and taxation at many points, which increases as the loss-inflated value of the produce increases.

Accompanying volume loss at all stages in production and marketing are the quality losses in the produce that finally reaches the ultimate consumer, seen, for example, in scabby potatoes from which a thick, wasteful paring must be removed, blemished fruit that is unappetizing and subject to rapid decay in the home, lettuce and cabbage from which a wastefully large number of leaves must be removed before reaching the uninjured centers, and construction timber with incipient stages of decay that inevitably mean costly, early replacement. Frequently, it is more economical for the consumer to pay a higher price for the best quality available, but either way, it is his bill to pay.

"The consumer always benefits from an abundance of production and should be more interested in maintaining loss-preventive measures that insure such abundance than growers as a group" (H. S. SMITH, et al., 1933). If production is curtailed and this is followed by high prices for the reduced crop, whatever the producer gains the consumers lose in money, and there is net social loss. The word "surplus" has been abused. Any quantity of produce that reduces the returns to producers is called a surplus, but rarely, if ever, is there a surplus in the social sense.

Today the world is our market, the world's vast population is the consumer. There can be no surplus so long as any part of that population is unfed or unclothed. Our economics and social understanding can no longer be limited to domestic supply and demand; so to limit them is to court world disaster. The principles of farm economy that once applied to an isolated America must be modified to conform to our new responsibility.

Any hazard that decreases production works hardship to some segment of society, creating damage that outweighs any limited profit to a favored few. It is the responsibility of agricultural science to reduce such hazards whenever and wherever they occur, let the economic chips fall where they may.

The science of plant pathology has the obligation and opportunity to relieve production of a major category of hazards, those due to plant disease. To accomplish this we must know the measure of the losses, so that our efforts at preventing them will be exerted at the most vital points. It has been the purpose of this book to attempt to blaze a trail into the relatively unexplored science of crop loss appraisal in the hope and belief that along this trail lie new and important opportunities for the science of plant disease prevention to make a more effective contribution, not to the farmer alone, but to human welfare.

POSTSCRIPT: LOOKING FORWARD

The need for accurate information on plant disease losses and their economic effects is very great. This need has not been met, yet the means for so doing are readily available. How may the resources of plant pathology be mobilized and activated toward this end?

A start would be formal recognition of this need by authoritative institution of a national committee charged with the responsibility of developing the understanding of plant disease losses and their effects. There are numerous public and private organizations that have a stake in such an undertaking and that may be expected to support it. Nomination to the committee should not be honorary but on the basis of interest, ability, and capacity for hard work, for the task is great. This committee might consider the following as worthwhile undertakings in the fulfillment of its mission:

First, the assembly and analysis of existing data on plant disease losses. Though fragmentary and often in error, the technical literature does contain much information on the destructiveness of plant diseases, and, with judgment, due allowance for over- or under-statement, and consideration of limits of applicability, this source of information can yield much of value.

At the same time there can be assembled existing data on methods of disease appraisal with respect to given crops and diseases, and constants for converting disease intensity into loss percent. The best of such methods and constants can be recommended for use in the future, to be supplemented in those cases in which existing information is inadequate.

Having assembled, selected, digested, and organized in useful form existing knowledge on losses and loss-appraisal methods, and made provision for supplementing and revising this knowledge on the basis of new publications as they appear, the committee will be conscious of many imperfections and lacunae in that knowledge, and will be concerned with means for amending them.

One of these means is to encourage those plant pathologists who are engaged in comprehensive studies of certain plant diseases to include, as a routine part of any thorough disease study, the measurement of loss and analysis of factors contributing to loss. The time has passed when any study of a plant disease that lays claim to being fairly thorough can dismiss the subject of economic importance with such a phrase as "very destructive". It is as though a plant pathologist passed over etiology by saying only "this disease is caused by a fungus".

A second means for adding to our knowledge of loss is to stimulate agricultural workers who are performing disease control tests or demonstrations to record their data in sufficient completeness that they bring out the amounts of loss associated with given intensities of disease. All that is needed is to indicate, in an understandable fashion, the amount of disease present and the difference in yields between treated, disease-free crops and untreated, diseased ones, yet it is dismaying to find how often experiments that have been well conducted at considerable expense are quite valueless from the standpoint of assaying loss, because of failure to make simple records of disease intensity and of yields of treated and control plants.

As a third method of supplementing our information on losses, a few young plant pathologists who are just entering their scientific careers might well be encouraged to specialize on loss appraisal. Here is a field of investigation worthy of the best in intellect and energy, with its far-reaching significance to human welfare. Such young men should be well trained in economics, as well as plant pathology and crop production, since we have here one of those new and profitable fields of endeavor that bridges two sciences. The same interests that stand to gain by loss appraisal studies may be expected to encourage such specialization by educational assistance.

Having catalyzed and set in motion a program of loss appraisal and interpretation, the national committee might gradually develop an educational program to make use of the findings. This could be done in several ways.

Among these would be a periodic survey training and experimental course for plant disease survey personnel. The meetings could be devoted to pooling information on survey methods and results, testing and standardizing disease measurement and estimation practices, and "calibrating the observer". Among the objectives of such groups would be the development of methods for making disease hazard appraisals of individual farms or localities, designed to aid in working out economic disease control programs and to provide a basis for pathological evaluation of farm land and for instituting crop disease insurance practices.

Meanwhile there is a large body of personnel engaged in agricultural survey work who have little or no training in plant pathoolgy or understanding of plant disease hazards. These men, economists, agronomists, crop scouts, crop insurance adjustors, railroad agricultural representatives, and others, could profit by attendance at short courses designed to offer them simple yet reliable guidance in assessing plant disease problems for what they actually are, economically. The organization and conducting of such short courses might be one of the most valuable contribu-

tions of the national committee.

The educational work, for plant pathologists and other agriculturists alike, would be notably aided by preparation of a manual or handbook giving in simple fashion the methods of reliable crop disease appraisal, facilitated by disease intensity charts, score cards, intensity-loss curves, tables, or ratios, and containing, for each major crop, explicit instruction on apprais-ing loss from principal diseases. The preparation of this manual would be a major accomplish-ment of the committee.

Finally, having in hand reliable and defensible statistics on the losses from plant diseases, the committee could reap the full benefits of its endeavors by making available these statistics to the many individuals needing them, to agricultural administrators who need to know the most strategic points toward which research and educational resources should be directed and who must substantiate their claims for support with reliable loss estimates, to industries that need to know the markets for their disease-preventive products, to the planners of new agricultural enterprises who must be advised of potential hazards, to the legislator, and to the man of the street, the consumer, who, most of all, stands to profit by the reduction of crop losses, and on whose goodwill and understanding the future of agricultural science depends.

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THE PLANT DISEASE REPORTER

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Division of Mycology and Disease Survey

BUREAU OF PLANT INDUSTRY, SOILS, AND AGRICULTURAL ENGINEERING

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UNITED STATES DEPARTMENT OF AGRICULTURE

SUPPLEMENT 194

SOME NEW OR NOTEWORTHY PLANT DISEASE RECORDS AND OUTSTANDING DEVELOPMENTS IN THE UNITED STATES IN 1949

Supplement 194 June 30, 1950

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THE PLANT DISEASE SURVEY
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Plant Industry Station — Beltsville, Maryland

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Compiled by Nellie W. Nance

Plant Disease Reporter
Supplement 194 — June 30, 1950

As in previous years this summary of outstanding plant disease occurrences in the United States has been taken for the most part from the reports to the Plant Disease Survey.

Weather of 1949. Since the disease situation appears to be directly correlated with the weather conditions, it seems desirable to review the weather of 1949 in the United States. (Monthly Weather Review. December 1949)

The winter of 1948-49 was a period of marked weather extremes which reached peak intensity during the first six weeks of 1949. This was the coldest winter on record west of the Continental Divide and the most severe on record in the northern Great Plains and generally throughout the Rocky Mountain and Pacific States. On the other hand it was the third warmest in most sections east of the Mississippi River. Extremes of precipitation were greatest in the Midwest and Great Plains where many sections received 200 to 400 percent of normal for the season.

Temperatures rose rapidly in the West during the last half of February and by the end of the month had returned to normal levels. The spring season (March-May), which was warmer than normal in practically all sections of the country, favored rapid growth of vegetation. Much above-normal precipitation in the Great Plains and lower Mississippi Valley was unfavorable to small grains and caused considerable delay in planting and cultivation.

Summer (June-August) was also warmer than usual in all sections, especially in the Lake Region and the New England and Middle Atlantic States where mean temperatures exceeded the normal by 4° to 6° F. Precipitation was below normal in the West, the northern Plains, and the Northeast but was generally normal or above in the southeastern quarter of the country. The cotton crop in the middle and eastern sections of the Main Belt suffered from lack of proper cultivation and from insect infestation due to prolonged intervals of rainy weather.

Autumn (September-November) was warmer than normal nearly everywhere in the United States, while only scattered sections received above-normal precipitation. This relatively warm, dry autumn was very favorable for the early maturity of most crops and enabled harvesting operations to make rapid progress.

The number of severe local storms during May and June was one of the highest on record and total damage was very high, but these storms were relatively few during the other months.

Disease Fluctuations. For the past several years it has been interesting to note the high degree of fluctuation in occurrence, prevalence and severity of plant diseases in the United States. In 1948 plant diseases were generally less prevalent than in an average year. There were no widespread epidemics and losses were much less than in 1947. Owing to the hot dry weather and adequate control measures late blight did not reach the epidemic proportions of the 1946 late blight attack. Victoria blight of oats seemed relatively unimportant as compared to 1947. In 1948 leaf rust of wheat was the lightest it had been for ten years. Tobacco blue mold and cucurbit downy mildew were generally lighter than in past years.

The year 1949, along with 1932, 1933, 1937 and 1947, was considered a severe blue mold year. There seemed to be a high coincidence between the intensity of blue mold in the five severe years and the above-normal January temperatures in those years at five southern points.

In 1949 plant diseases caused a greater loss to small grains in Texas than in any year of the history of the State. In some oat-producing States it seemed that adverse weather, nitrogen starvation and insect attacks were more important in reducing yields than parasitic diseases. Stripe was the most serious disease of barley in California in 1949. It was much more prevalent than in any of the past 15 years. Mosaic of a western type was found in Kansas, causing much damage. For wheat leaf rust 1949 seemed to be average.

Surveys indicated that citrus canker has been entirely eliminated. Oak wilt, one of the most destructive tree diseases, became more widespread in 1949.

The worst epidemic of cucurbit downy mildew since 1938 occurred this year in South Carolina.

During the year 19 diseases were reported in States where they had not been found before on a particular host. (Table 1). Diseases found or reported in this country for the first time in 1949 or found on new hosts are listed in Table 2.

Table 1. Diseases reported in States where they had not been found or reported on a particular host until 1949.*

Host Disease (Cause)	Where found	Remarks
BARLEY Downy mildew (Sclerospora macrospora)	Missouri	Believed to be the first report of the fungus from Missouri and the Middle West. Scattered plants in a low wet area found to be infected. (PDR 34: 29-30)
CORN Leaf rust (Puccinia polysora)	Indiana	Found along the Ohio River (PDR 34: 98-99)
PEACH Bitter rot (Glomerella cingulata)	Texas	Found on 10 to 25% of the fruits on five peach trees at the Tomato Disease Laboratory near Jacksonville. (PDR 33: 389)
MIMOSA Fusarium wilt (F. oxysporum f. perniciosum)	New Jersey	Organism isolated from a diseased mimosa tree at Cape May in July 1949. (Jour. N. Y. Bot. Gar. Oct. 1949)
SNAPDRAGON Downy mildew (Peronospora antirrhini)	New York	Found affecting 2 to 3% of blooming plants in a greenhouse near Troy in February. (PDR 33: 234)
CAMELLIA JAPONICA Flower spot (Sclerotinia camelliae)	Oregon	Disease introduced into California from the Orient a few years ago. (see p. 372)
CHRYSANTHEMUM Ascochyta ray blight (Mycosphaerella ligulicola)	California	Perfect stage of Ascochyta chrysanthemi. (see p. 372)
POPPY Bacterial blight (Xanthomonas papavericola)	Arizona	Reported to be common in poppies in flower gardens. (see p. 372)
COTTON Root constriction (Physiological)	Arizona	Previously reported from California and Texas. (PDR 33: 302)
Browning and stem break (Polyspora lini)	Arizona	Isolated from specimens sent in from Deer Valley and Safford. (PDR 33: 302)

*For new State records of grasses see PDR 33: 147-158, 259-270.

Table 1. (Continued)

Host Disease (Cause)	Where found	Remarks
BUDDLEIA ASIATICA, BUTTER-FLY-BUSH		
"Scab" (Cladosporium heugelinianum)	Virginia	This specimen may be the second finding of the fungus in America. (PDR 33(6): 274)
GREEN ASH		
Verticillium wilt (Verticillium albo-atrum)	Colorado	Common on elms and maples but first isolation from ash. (PDR 34: 83)
OAK		
Wilt (Chalara quercina)	Indiana	Its prevalence in the State is not known. (PDR 33: 332)
STAGHORN SUMAC		
Fusarium wilt (Fusarium oxysporum f. rhois)	Virginia Connecticut	Not reported from any other localities to date or any other species of Rhus. (see p. 376)
Leaf spot (Alternaria tenuis)	Colorado	Limited to a few trees in widely separated areas in Denver. (PDR 34: 83)
ONION		
Smut (Urocystis cepulae)	California	Found in a two-acre onion plant bed in Stanislaus County. This plot of land had been used as an onion plant bed for 8 years. (PDR 33: 451-452)
CABBAGE		
Yellows (Fusarium oxysporum f. conglutinans)	Louisiana	Occurred in fall of 1948. No explanation as to how and when the fungus was introduced. (PDR 33: 233)
SWEETPOTATO		
Mottle necrosis	Louisiana	Recorded for first time on July 29. Fungus isolated appeared to be different from Pythium ultimum or P. scleroteichum. (PDR 34: 61)
POTATO		
Powdery mildew (Erysiphe cichoracearum)	Washington	Perithecial stage. Since this is the first clearly identifiable case of this fungus on potatoes in natural conditions, a description is given. (PDR 34: 140-141)

Table 2. Diseases found or reported in this country for the first time in 1949 = *; diseases found on new hosts = **. New disease strain = ***.

Host Disease (Cause	Where found	Remarks
BROOMCORN		
Septoria leaf blight *	Illinois, perhaps first reported in U. S.	Found in Douglas County. Three fields showed 100% infection. (PDR 33: 384)
WHEAT		
Cladosporium herbarum *	Kentucky	Reported to cause a serious disease in Europe. (PDR 34: 24-26)

Table 2. (Continued)

Host Disease (Cause	Where found	Remarks
ANNUAL YELLOW SWEET-CLOVER ** CRIMSON CLOVER ** REDROOT AMARANTHUS ** Sugar beet mosaic (Virus)	California	Naturally infected (see p. 369)
RED CLOVER Anther mold * (Botrytis anthophila)	Oregon Washington	Found on seeds. (PDR 33: 396)
LADINO CLOVER Yellow patch *** (Marmor medicaginis H. var. Ladino n. var.)	Northeastern U. S.	From host range and other properties, the virus was identified as a strain of alfalfa mosaic virus different from any described previously. (see p. 370)
TAHITI LIME Dodder galls ** (Cuscuta americana)	Florida (1948)	Similar to Sphaeropsis tumefaciens. Leads to stunting of twig growth. (Phytopath. 39: 616-620)
SOUR CHERRY Raspleaf ** (virus)	Colorado	Commonly considered to be present only on sweet cherries. (PDR 34: 57)
FLAMERAY GERBERA Gray mold ** (Botrytis cinerea)	Pacific Northwest	Found growing on this new host in one of the local greenhouses. (Phytopath. 39: 949-950)
GARDEN STOCK Leaf spot * (Alternaria raphani)	California	This disease has caused complete destruction of several small plantings. (see p. 372)

DISEASES OF CEREAL CROPS

L. M. Josephson and D. A. Reid, reporting on small grain diseases in Kentucky in 1949, stated that in general, many of the common diseases were not so heavy as in 1948, but several of the generally more minor diseases caused damage in localized areas. Central Kentucky was relatively dry during the spring months, while in some areas in the western part of the State excessive rainfall delayed field work at times and promoted incidence of certain diseases. (PDR 34(1): 24-26).

Plant diseases caused a greater loss to small grain in Texas in 1949 than in any year of the history of the State, according to reports by I. M. Atkins. He estimated losses for the State as follows: wheat 20.5 percent, oats 21.9 percent, barley 7.8 percent. (PDR 34(2): 40-42).

Curtis W. Roane reported incidence of diseases of small grains in Virginia in 1949. Leaf and stem rusts, powdery mildew, and the smuts, caused the greatest toll and are severe each year. Other diseases were only of local concern. (PDR 33(12): 480-482).

R. W. Leukel reported results of cooperative field experiments, which were carried out at several stations in seven Southern States to determine the relative effectiveness of certain fungicides for the control of several seed-borne diseases of cereals. (PDR 33(7): 295-299).

AVENA SATIVA. OATS: H. R. Rosen contributed the annual report on oat diseases in Arkansas. He stated that while parasitic diseases were common throughout the State, as appeared evident in a statewide survey conducted in May and June, it seemed that adverse weather, nitrogen starvation, and insect attacks were more important in reducing yields in 1948-49 than parasitic diseases. In any case, the average State yield of 27 bushels per acre in 1949 marks the first year in the last four in which there was no increase in the average yield over the immediate preceding years, and actually showed a reduction of 5.5 bushels from the 1948 yield. (PDR 34(2): 43-44).

Helminthosporium victoriae, blight, and Puccinia coronata avenae, crown rust. In Florida, S. C. Litzenberger reported that during the latter part of January, 1949, a thorough survey was made of the prevalence of these two major oat diseases. Blight and crown rust Race 45 or similar races were found present on susceptible varieties at all locations checked. The severity of infection centered around Gainesville and decreased somewhat to the northward. (PDR 33(3): 146).

T. R. Stanton presented available information concerning 13 varieties of oats resistant to Victoria blight now available for growing or for planned early distribution. (Circ. U. S. Dept. Agr. 795, 7 pp. 1949).

HORDEUM VULGARE. BARLEY: Helminthosporium gramineum, stripe, was reported by Suneson as the most serious barley disease in California this year. It was much more prevalent than in any of the past 15 years. At least one-fourth of the 1949 northern California acreage was sown without any kind of seed treatment. One 80-acre field of barley averaged about 70 percent rust. (PDR 33(7): 300).

Sclerospora macrospora, downy mildew, first report from Missouri and Middle West, see Table 1.

Mosaic (virus). Preliminary tests reported by D. F. Wadsworth indicated that a mosaic found in a single barley plant in Oklahoma was different from wheat mosaic. (PDR 33(12): 482-483).

LINUM USITATISSIMUM. FLAX: Fusarium oxysporum f. lini, wilt. Houston and Knowles reported the fifty-year survival of the Fusarium wilt organism in the absence of flax culture in the coastal area of San Mateo County, California. The ability of the fungus to survive at such a high level of infestation in the absence of flax culture was found to be due to the presence of a "wild" flax growing in that area. Other diseases were found occurring naturally on the uncultivated flax. (PDR 33(1): 38-39).

Mycosphaerella linorum, pasmo, was unusually destructive to seed flax in South Texas during the spring of 1949, according to Dunlap and Harrison. The first occurrence of the disease was noted in February. Its unusually early appearance this year resulted in the plowing under of many fields several weeks before harvest. Some yields of as low as seven or eight bushels per acre were obtained in the counties most seriously affected. (PDR 33(10): 402-403).

SORGHUM VULGARE. SORGHUM: E. S. Luttrell described grain sorghum diseases in Georgia in 1949. Humid weather combined with early planting favored the development of a number of leaf, head and stalk diseases of grain sorghums in variety tests. Seedling diseases were not an important factor. Bacterial stripe (Pseudomonas andropogoni), zonate leaf spot (Gloeocercospora sorghi), gray leaf spot (Cercospora sorghi), anthracnose (Colletotrichum graminicolum), and rust (Puccinia purpurea) were important foliage diseases on some or all varieties. At one location stalk rots were serious, making harvesting difficult and causing losses in grains. (PDR 34(2): 45-52).

SORGHUM VULGARE VAR. TECHNICUM. BROOMCORN: Septoria leaf-blight, see Table 2. Benjamin Koehler and C. M. Woodworth reported that the warm humid weather that prevailed during the summer made conditions favorable for several broomcorn diseases to flourish in Illinois. The principal ones were anthracnose (Colletotrichum graminicolum), Septoria leaf blight, Helminthosporium leaf blight, and bacterial stripe blight (Pseudomonas andropogoni), anthracnose being the most serious one. Herbarium specimens showed that Septoria blight occurred in the Arcola area as far back as 1943, but it was not recognized as Septoria until this year. Helminthosporium developed during August, but did not become as serious as Septoria. (PDR 33(10): 385-386).

TRITICUM AESTIVUM. WHEAT: Puccinia rubigo-vera var. tritici, leaf rust. Chester and Wadsworth made the ninth experimental forecast of wheat leaf rust in Oklahoma. (PDR 33(5): 223-226).

Mosaic (virus). According to a survey reported by Hurley Fellows wheat mosaic of a western type was found from the northern to the southern borders of western Kansas, causing much damage. (PDR 33(10): 356-358). Experiments in the infested areas in Kansas in the 1930's indicated that infested fields do not remain contaminated from one season to the next.

ZEA MAYS. CORN: Aerobacter dissolvens (Erwinia carotovora), bacterial stalk rot, appeared suddenly and was widespread in southern Illinois and as far north as Champaign County. The disease was much more prevalent in 1949 than in previous years. No control measures are known. (Boewe, G. H., PDR 33(9): 342).

Pythium butleri, stalk rot, was reported in three counties in Kentucky by Valleau and Diachun. Growers claimed that they had never seen the disease in river-bottom corn before. They stated that the exceptionally high temperatures and high humidity brought about conditions ideal for infection by the fungus. On an average the loss was very small, but in small areas as high as 50 percent of the plants were rotted and fallen over. (PDR 33(9): 341).

Arnold J. Ullstrup, in reporting on corn diseases in Indiana in 1949, stated that the general increase in prevalence and severity of the more common corn diseases, and the occurrence of a few unusual diseases of this crop seemed worthy of comment. Rust (Puccinia polysora) was found for the first time in Indiana along the Ohio River. Northern corn leaf blight (Helminthosporium turcicum) occurred in epidemic form. The disease situation appeared to be directly correlated with the weather conditions that prevailed during the growing season. (PDR 34(4): 98-99). Ullstrup reported Pythium stalk rot from nearly every section of Indiana. The onset of the disease was preceded by two weeks of hot humid weather in which maximum temperatures were in excess of 90° F. The disease had occurred before in Indiana, but only in insignificant proportions. (PDR 33(8): 331).

DISEASES OF FORAGE AND COVER CROPS

GRAMINEAE. GOLF GREENS: Pythium butleri, "grease spot," caused considerable concern to numerous greenkeepers in Indiana and the Chicago district in 1949, according to Sharvelle and Likes (Midwest Turf 3(4): 3, 1949). Golf greens that are almost surrounded by trees or located in low valleys are particularly susceptible to the disease. They state that if all conditions are favorable the disease is capable of destroying 30 to 40 percent of a putting green surface within 24 hours. In 1949 application of iron sulfate at the rate of one pound in 30 gallons of water applied to 5000 square feet of turf definitely appeared to stop the Pythium disease.

MEDICAGO SATIVA. ALFALFA: In Virginia during the period March 21 to 25 alfalfa and clover fields were visited in six Virginia Counties, by Fenne and others. Sclerotinia sclerotiorum was found on alfalfa in most of the areas visited except in Orange County. Black stem (Ascochyta imperfecta) was found generally distributed in almost every alfalfa field examined and in many instances had already caused severe injury. The disease was especially destructive on new stands of alfalfa. Ditylenchus sp., stem nematode, was found widespread on one farm in Henrico County. The disease was more severe this year and apparently was responsible for killing out the stands of susceptible varieties. Corynebacterium insidiosum, bacterial wilt, was found in James City and Henrico Counties. (PDR 33(6): 255-257).

SOJA MAX. SOYBEAN: Of the nine diseases occurring in Iowa in 1949, J. M. Crall reported that only brown stem rot (Cephalosporium gregatum) and stem canker (Diaporthe phaseolorum var. batatatis) caused serious loss. Distribution of the known occurrences of these two diseases in the State is shown on maps. (PDR 34(4): 96-97).

TRIFOLIUM SPP. CLOVER: In Virginia, during the period March 21 to 25 clover and alfalfa fields were visited in six Virginia Counties, by Fenne and others. Sclerotinia trifoliorum, stem rot, was readily found on Crimson and Red clovers, and in Culpeper County it was causing serious injury on Ladino clover. In general Ladino clover was less seriously affected by the disease than other clovers. The most severe injury caused by Sclerotinia on the entire trip was observed on a legume-grass farm in Fairfax County. (PDR 33(6): 255-257).

TRIFOLIUM INCARNATUM. CRIMSON CLOVER: Sugar beet mosaic virus. C. W. Bennett reported three species of plants, apparently not hitherto recorded as hosts of sugar beet mosaic virus, were found naturally infected in southern California fields, namely Amaranthus retroflexus, Melilotus indica, and crimson clover (Trifolium incarnatum). The disease was transmitted

experimentally by means of Myzus persicae from sugar beets to these species, as well as the following, also apparently new hosts: Beta patellaris, Browallia speciosa, Nicotiana quadrivalvis and its var. multivalis, N. clevelandi, Phacelia campanularia, Little Gem garden pea, and Samolus parviflorus. Sugar beets were infected from each of these plants by juice inoculations. (Phytopathology 39(8): 669-672).

TRIFOLIUM PRATENSE. RED CLOVER: Botrytis anthophila, anther mold. The first record of anther mold on red clover in the United States was reported by John R. Hardison from the Pacific Northwest. R. A. Silow suggested the presence of B. anthophila in this country, since he had reported the disease in Great Britain on red clover grown from seed of American origin. (PDR 33(10): 396).

TRIFOLIUM REPENS. LADINO CLOVER: Kreitlow and Price reported a new virus disease of Ladino clover known as yellow patch, which was prevalent in north-eastern United States. The virus is given the trinomial Marmor medicaginis H. var. Ladino n. var. (Phytopathology 39(7): 517-528).

DISEASES OF FRUIT CROPS

CITRUS SPP. Xanthomonas citri, citrus canker. The 1947-49 survey for citrus canker in Texas and Arkansas had completely negative results, according to W. A. McCubbin. Since the discovery of this destructive pest in 1913 the eradication campaign started by the Federal and State governments has succeeded in eliminating this bacterial parasite from nurseries and commercial citrus in 7 infected States (Alabama, Florida, Georgia, Louisiana, Mississippi, South Carolina and Texas) within a few years. (PDR 33(10): 394-395).

Hurricane damage. L. Carl Knorr reported the first summary of loss estimates to Citrus caused by the Florida hurricane of August 27, 1949. The greatest damage was to grapefruit, already the smallest crop since 1939-40. The greatest loss to citrus occurred by the tearing off of the fruit. (PDR 33(10): 391-394).

CITRUS AURANTIFOLIA. TAHITI LIME: L. Carl Knorr described a gall of the branches of Tahiti lime in Florida, similar to that caused by Sphaeropsis tumefaciens, and attributed its formation to Cuscuta americana L. He pointed out that such dodder galls lead to a stunting of twig growth and are the seat of haustoria that remain to regenerate aerial vines after the dodder has ostensibly been eradicated. Control of dodder in limes necessitates the pruning out of infected wood or the hatracking of the tree. (Phytopath. 39(8): 616-620).

FRAGARIA SP. STRAWBERRY: Diachea leucopoda, slime mold, was found in Texas in May 1949 according to E. M. Hildebrand. The fungus had grown up the plant surface involving half or more of the leaf surface from the soil line and had covered the leaves to the extent that shading was seriously affecting the vitality of the plants. (PDR 33(7): 301-302).

MALUS SYLVESTRIS. APPLE: Venturia inaequalis, scab. Kirby reported much earlier than usual development of apple scab spores in Pennsylvania. (PDR 33(4): 205). Goldsworthy, Dunegan and Wilson reported that the experiments in 1947-48-49 seasons when apple scab was generally very prevalent and difficult to control in many orchards, appeared to indicate that the use of eradicant fungicides applied in two steps is of promise in the control of this disease, first by eliminating a great deal of the ascospore inoculum in the diseased leaves that lie on the orchard floor, and, second by eradicating the early infections that develop on leaves and fruit from the small amount of ascospore inoculum that escapes the floor treatment. These tests appeared to confirm previous experiments showing that the use of eradicants on the floor of the orchard does not eliminate the need of subsequent sprays to control the disease. These tests likewise showed that the use of an eradicant at the time of bloom or later is also inadequate for controlling the disease in seasons of epidemic, with one or several applications. The experiments indicated that if the eradicants are used in a logical sequence, the problem of scab control is simplified. (PDR 33(8): 312-318).

PRUNUS ARMENIACA. APRICOT: Monilinia laxa, brown rot blossom blight. Neither Bordeaux mixture nor petroleum oil had a significant effect on the eradicative action of monocalcium arsenite against M. laxa on apricot, at concentrations used in investigations reported by E. E. Wilson from California. (PDR 33(7): 287-289).

PRUNUS CERASUS. SOUR CHERRY: Sulfur injury to sour cherry petals, observed in Pennsylvania this year, was probably indirect, the primary cause of the actual petal killing was due to low temperature, according to F. H. Lewis and R. S. Kirby. In 1950, lime sulfur will likely be replaced by Bordeaux mixture or one of the proprietary copper compounds. (PDR 33 (7): 290).

Spray injury. In observations reported by D. Petersen and D. Cation from Michigan, the amount of spray injury to sour cherry petals during warm weather was affected more by the time of day when applications were made than by the different materials used. (PDR 33(12): 479-480).

Ring spot and sour cherry yellows virus diseases were present and widespread in Colorado. (PDR 34(2): 57).

PRUNUS PERSICA. PEACH: Glomerella cingulata, bitter rot. Young sent in the first report of bitter rot on peach from Texas. However, he stated that bitter rot of apple had been serious in orchards. (See Table 1.)

Cross inoculations with G. cingulata from peach and from lupine showed that strains isolated from one host can infect the other, according to John L. Weimer and J. C. Dunegan. (PDR 33 (11): 416-417).

Xanthomonas pruni, bacterial spot. Curtis L. Mason reported that very favorable results were obtained from sodium hypochlorite applied as a spray for control of peach bacterial wilt and brown rot, Monilinia fructicola, in Arkansas. He suggested that this material may have wide use in the control of plant diseases. (PDR 33(8): 319-320).

Monilinia fructicola, brown rot. According to Panos L. Poulos experimental use of sodium hypochlorite for control of peach brown rot in Delaware was not successful. (PDR 33(11): 413-415).

Preliminary experiments in Michigan with the antibiotic Acti-dione for the control of peach brown rot and cherry leaf spot, Coccomyces hiemalis, are summarized by D. Petersen and D. Cation. (PDR 34(1): 5-6).

Pratylenchus sp., meadow nematode, was reported by Frank D. Johanson in Connecticut. The rotting of the roots was explained as being caused by secondary fungus or bacterial infection. These rot organisms gained entrance through lesions made in the rootlets by the nematode. Pratylenchus has been found to injure roots of many different plants. (PDR 33(4): 204-205).

VITIS SPP. GRAPE: Winter injury. For the first time in the memory of Concord grape growers in the area, winter injury appeared in the vineyards around Kennewick, Washington, according to R. E. Jones. Attempts were made to single out some one factor as the immediate cause of vine damage to correlate with the extremes of temperatures which were experienced in the area during the winter 1948-1949. No single cause has been found although the vines which previously had been the most vigorous were seemingly hardest hit. At least a portion of the damage occurred early in the fall when a hard freeze attack struck the area before the fruit was harvested. The winter weather that followed was probably the greatest factor involved. During the six-weeks' period from December 20 to February 10, two periods of extremely low temperature occurred. The extremes ranged to 15^{o} below zero. Tests showed that the ground was frozen to a depth of 33 to 36 inches during this period. Jones stated that as far as production is concerned the damage will be felt for several years. (Better Fruit 44(1): 7, July 1949).

RIBES SPP. CURRANT: Cronartium ribicola, blister rust. Canadian black currants showed blister rust immunity under field conditions in Connecticut, according to Glenn G. Hahn and Alton Miller. (PDR 33(6): 275-276). Observations on widespread tests of immune ribes reported by Hahn give no evidence that physiologic races of the white pine blister rust fungus exist in North America. (PDR 33(7): 291-292).

DISEASES OF NUT CROPS

P. W. Miller reported on the incidence of diseases of filbert and walnut in the Pacific Northwest in 1949. (PDR 34(2): 38-39).

CARYA ILLINOENSIS. PECAN: Cladosporium effusum, scab. According to John R. Large, on February 25, 1949, sporulating scab lesions on leaflets of volunteer seedling pecan trees were observed near Monticello, Florida. Several pecan trees had leaflets one-third grown on this date. Due to warm weather budding appeared about three weeks earlier than usual. (PDR 33(4): 206).

JUGLANS SIEBOLDIANA. JAPANESE WALNUT: Witches'-broom (virus). Julian H. Miller and G. E. Thompson reported this virus disease on Japanese walnuts in Georgia. The disease had been prevalent since 1938. (PDR 33(12): 455).

DISEASES OF ORNAMENTALS

F. P. Hubert and W. H. Wheeler reported and listed diseases found in domestic-grown flower bulbs, during a survey made by the Division of Domestic and Foreign Plant Quarantines. (PDR 34(2): 53-55).

ALBIZZIA JULIBRISSIN. MIMOSA: Fusarium oxysporum f. perniciosum, wilt, according to P. P. Pirone, has been known since 1930. It is now known to occur from Maryland to Georgia. Up to 1949 the northernmost point of its occurrence was Silver Springs, Maryland. In July 1949, Pirone isolated the fungus from a diseased tree at Cape May, New Jersey. Although this new location is no farther north than Silver Springs, it is nearly 100 miles eastward, thus greatly extending its present range. This is the first report of its occurrence in New Jersey. (Jour. N. Y. Bot. Gar. October 1949).

ANTIRRHINUM MAJUS. SNAPDRAGON: Peronospora antirrhini, downy mildew, see Table 1.

AZALEA: Exobasidium azaleae. Unusual incidence of this disease was reported by E. C. Tullis in Texas. It seemed to have followed up two dry seasons with extreme cold during the winter. There was also extra heavy rainfall during the spring season when these plants were putting on new growth. (PDR 33(5): 234).

CAMELLIA. CAMELLIA: Sclerotinia camelliae, flower spot, was introduced into California from the Orient a few years ago. The disease has invaded Oregon plantings. It has been found in plantings at Eugene, Albany, Oregon City, and Portland. (PDR 33(10): 404).

CHRYSANTHEMUM SPP.: Mycosphaerella ligulicola, Ascochyta ray blight, has been an important disease in North Carolina for more than 40 years without much spread to other areas according to Kenneth F. Baker and others. It occurs also in South Carolina, Mississippi, Florida, and Maryland. H. N. Hansen and W. C. Snyder observed Ascochyta pycnidia and Mycosphaerella perithecia on dead stem bases of commercial chrysanthemums from San Mateo County in March 1949. This is the first report of the disease from California, and this record is therefore of unusual interest since it shows that the fungus will persist in an area of unfavorable climate where the natural flower infections are not known to occur. M. ligulicola is described by the writers as the perfect stage of Ascochyta chrysanthemi. Control measures to reduce inoculum carryover and the disease in the field have been tried out. (Phytopath. 39(10): 789-805).

ERYTHRONIUM GRANDIFLORUM VAR. PALLIDUM. LAMBSTONGUE FAWNLILY: Botrytis elliptica. MacLean and Shaw reported that B. elliptica was found associated with a stem, leaf and petal spotting of E. grandiflorum var. pallidum growing in its native habitat in Garfield County, Washington. (Phytopath. 39(11): 949-950).

GERBERA JAMESONII. FLAMERAY GERBERA: Botrytis cinerea, gray mold, new host. (See Table 2.)

MATHIOLA INCANA. GARDEN STOCK: Alternaria raphani, leaf spot. Lily H. Davis and others reported the occurrence of this leaf spot in California. The disease was first observed in commercial fields of garden stock in June 1946. It was not particularly damaging at that time, but growers reported severe losses later in that and the following year. In October 1948 it was again observed and has since caused complete destruction of several small plantings. They state that apparently this is the first report of the fungus on Mathiola in this country. (PDR 33(11): 432-433).

PAPAVER SPP. POPPY: Xanthomonas papavericola, bacterial blight. From Flagstaff, Arizona diseased oriental poppies were sent in for identification according to J. B. Brown and Alice M. Boyle. The cause was found to be bacterial blight. The disease was reported to be common in poppies in flower gardens, but this was the first identification of the bacterium in the State. (PDR 33(7): 302-303).

PELARGONIUM SP. PELARGONIUM: Pseudomonas erodii, bacterial leaf spot, is described by E. M. Hildebrand and A. C. Yezak in Texas on Pelargonium. The wild crane's bill, Erodium texanum, a plant native to central Texas, is the only wild plant known to be susceptible to infection by this organism. Susceptible species have been found only in the two genera, Erodium and Pelargonium. (PDR 33(7): 293-294).

DISEASES OF SPECIAL CROPS

AGARICUS CAMPESTRIS. MUSHROOM: Peter A. Ark discusses occurrence and control of mushroom diseases in California. Dactylium sp. was serious in one house and caused 50 percent loss in the crop. Verticillium sp., causing the so-called dry bubble disease, was found in a great number of mushroom houses where casing soil is not sterilized prior to filling the beds. It was especially severe in houses with poor sanitation. (PDR 33(4): 181-182).

Ditylenchus sp. Lambert, Steiner and Drechsler reported that examination of compost from mushroom establishments in Pennsylvania and Delaware indicated that the "Cephalothecium disease" of cultivated mushrooms, in which a surface mold is associated with a destruction of the mushroom mycelium, is really due to a nematode (Ditylenchus sp.). The mold, isolated from three locations, was identified as Arthrobotrys superba. (PDR 33(6): 252-253).

ARACHIS HYPOGAEA. PEANUT: In Alabama, Coyt Wilson reported that available evidence indicated that the value of seed protectants for peanuts lies in the prevention of seed rot between the time of planting and germination. (PDR 34(4): 87-95).

Sclerotium rolfsii, see under Nicotiana tabacum.

Several species of parasitic nematodes (Tylenchorhynchus claytoni, Criconemoides sp., Pratylenchus leiocephalus, Aphelenchoides spp., Dorylaimus sp., Seinura tenuicaudata, Pratylenchus leiocephalus var., Xiphinema americanum) were found to be associated with poor growth of peanuts in Georgia and dark pock marks on the shells, according to Lytton W. Boyle. (PDR 34(3): 61-62).

GOSSYPIUM SP. COTTON: Ascochyta gossypii, Ascochyta blight was reported widespread in Georgia by D. D. Morey and J. H. Miller. There was an average reduction in stand of 25 to 85 percent. Later in the season when temperatures were higher and there was less rain the disease was very appreciably retarded. The most striking fact observed was the control obtained by rotations. (PDR 33(8): 310-311).

Polyspora lini and root constriction, see Table 1.

Sclerotium rolfsii, boll rot, caused an unusual type of damage to cotton bolls in Alabama in August 1949. Only full grown bolls were attacked, which were 1.5 to 2.0 feet from the soil surface. (James A. Lyle, PDR 33(11): 441).

MENTHA SPP. MINT: C. A. Thomas reported observations on diseases of medicinal and other special crops. Verticillium wilt remained the No. 1 problem for mint growers in Indiana and Michigan. He stated that the only satisfactory control of wilt appears to be the development of resistant varieties. (PDR 33(12): 453-454).

NICOTIANA TABACUM. TOBACCO: Peronospora tabacina, blue mold (downy mildew) was observed in a Cook County seedbed January 11, 1949, according to John G. Gaines. He stated that this was the earliest seasonal observation ever made of this disease in a commercial Georgia seedbed. The grower reported seeing disease symptoms in this bed as early as January 8. (PDR 33(3): 166-167). Georgia and Florida tobacco seedbeds escaped severe damage because of unfavorable weather for the disease later. In contrast in North and South Carolina blue mold occurred in the worst attack in ten years. Contributing factors of the epidemic seemed to be early appearance, favorable weather conditions and indifference of growers to control measures because of slight occurrence last year. Paul R. Miller pointed out that up to April 26 the incidence of blue mold had provided a double object lesson in control, (1) certainty of control by recommended materials used as recommended, (2) the necessity of not basing control measures on last year's occurrence.

April weather conditions in Florida were favorable for blue mold and the most severe epidemic developed in the fields of the flue-cured tobacco that has ever occurred. A downy mildew was also found in North Carolina in a plant bed of eggplant, pepper and tomato seedlings, which was located 300 yards from a tobacco bed in which blue mold was active. (PDR 33(4): 238-243). For distribution of tobacco blue mold in 1949, see PDR Supp. 188, page 299, December 1949.

H. E. Heggestad and E. E. Clayton, reporting on the occurrence of black shank (Phytophthora parasitica var. nicotianae) and other diseases in Tennessee, stated that black shank was found in Eastern Tennessee for the first time. A survey showed infection on about 35 farms in Greene County. (PDR 34(1): 23-24).

Pseudomonas tabaci, wildfire, was observed in widespread occurrence in tobacco plant beds of East Tennessee this spring, according to Howard E. Heggestad. Frequent rains favored disease development. This unusual widespread occurrence of wildfire in plant beds is accociated with increased prevalence of the disease noted in the field in recent years. (PDR 33(7): 286-287).

Sclerotium rolfsii, sclerotial blight. During the second week of August, S. B. Fenne reported this disease severe in many tobacco and peanut fields in Sussex, Greensville, and Brunswick Counties, Virginia. He stated that sclerotial blight was more severe on peanuts than he had ever seen it. Farmers felt there would be a severe loss to their peanut crops. In several tobacco fields 5 percent of the plants were killed. (PDR 33(10): 403).

SESAMUM ORIENTALE. SESAME: Pseudomonas sesami, leaf spot or blight. In the experimental plantings of the Texas Research Foundation at Renner a serious leaf spot or blight condition developed on sesame seedlings about June 10. The organism was identified as P. sesami. (E. M. Hildebrand, PDR 33(8): 331).

DISEASES OF TREES AND SHRUBS

W. A. Campbell and others prepared an annotated selective list of wood-decaying fungi of Georgia. Many of the wood-decaying species were collected in the fall of 1949. (PDR 34(5): 128-134).

George H. Hepting and E. Richard Toole listed some Southeastern tree diseases observed in 1948 and 1949. The more prevalent diseases in 1949 included mimosa wilt, oak dying, white pine blight, littleleaf of shortleaf pine, redbud canker, root and heart rots of redcedar, and sycamore anthracnose. (PDR 34(5): 135-137).

AESCULUS HIPPOCASTANUM AND A. OCTANDRA, HORSECHESTNUT AND BUCKEYE: Glomerella cingulata, anthracnose, on buckeye in Missouri was reported by E. S. Luttrell as a leaf disease of little importance. On horsechestnut he reported it to be a serious disease, causing a dieback of the branches and severe cankers on the branches and trunk in addition to leaf lesions. (PDR 33(8): 324-327).

BUDDLEIA ASIATICA. William W. Diehl reported that a specimen of B. asiatica with numerous sooty spots on the lower surface of the leaves was found by C. L. Lefebvre on March 23, 1949 in a greenhouse in Clarke County, Virginia. The effect was that of "scab". He referred the organism to Cladosporium heugelinianum Thüm., stating that the specimen may be the second finding of the fungus in America. One other specimen collected at Wilmington, Delaware in 1926 was so identified. (PDR 33(6): 274).

FRAXINUS PENNSYLVANICA LANCEOLATA. GREEN ASH: Verticillium alboatrum, see Table 1.

FRAXINUS VELUTINA. ARIZONA ASH: Gloeosporium aridum, anthracnose. Donald M. Coe and Willis W. Wagener reported (May 1949) an outbreak of ash anthracnose, which apparently was unknown in the State before 1947, in the Central Valley region of California in 1948. A delayed spring, marked by prolonged rains and cool temperatures, provided very favorable conditions for the development and spread of this disease in 1948. (PDR 33(5): 232).

JUNIPERUS SPP., JUNIPERS: Phomopsis juniperovora, cedar blight. According to Glenn G. Hahn the scant number of known junipers reported to be resistant to cedar blight is further reduced as the result of tests that have shown the Dundee Juniper, Juniperus virginiana var. hilli and two species of J. virginiana, to be susceptible to cedar blight under experimental conditions. (PDR 33(8): 330).

LIQUIDAMBAR STYRACIFLUA. SWEETGUM: Leader dieback was noted on sweetgums in Georgia in the spring of 1948. This "new" disease of sweetgum appeared more widespread in 1949 than in 1948 according to Kenneth H. Garren, who described the disease. Neither the causal agent nor the importance of this disease has yet been definitely established. (PDR 33(9): 351-353).

PINUS SPP. PINE: Ralph M. Lindgren and Berch W. Henry discussed some promising soil treatments for controlling root disease and weeds in a southern pine nursery. (PDR 35(5): 228-231).

PINUS MONTICOLA. WESTERN WHITE PINE: *Scopularia serpens* (?). While engaged in investigations of "pole blight", a disease of unknown cause, attacking western white pine in Idaho, Montana, and Washington, Gill and Andrews made several hundred isolations to determine what fungi, if any, were involved. Several members of the genus *Scopularia* were isolated. One of them resembled *S. serpens* more strongly than it did any species previously reported on western white pine from this region. Preliminary tests indicated that it may be parasitic on bark as well as wood. The fungus was isolated from stems and roots of diseased as well as apparently healthy trees at several widely scattered points throughout the range of the host (PDR 35(5): 227).

P. PONDEROSA. PONDEROSA PINE: *Scirrhia acicola*, brown spot needle disease. Of the three fungi reported and described by E. S. Luttrell as associated with decline of *Pinus ponderosa* in Missouri, the brown spot organisms seemed to be the primary cause. The abundance of this fungus and the marked stunting of the trees indicated that the brown-spot disease had been present for a number of years. Since brown spot has been considered serious only as a seedling disease of southern pines, he pointed out that its severity here on older trees may indicate that the ponderosa pine is inherently more susceptible. *Phaeocryptopus pinastri* and *Lophodermium pinastri*, the other two fungi associated, were obviously of secondary importance. (PDR 33(10): 397-401).

QUERCUS SPP. OAK: *Chalara quercina*, oak wilt, is one of the most destructive tree diseases, according to Roy A. Young. Large oak trees may be killed within a few weeks after the first appearance of wilt symptoms. The disease was found to be caused by this fungus in 1942. However, little is known about the manner in which this pathogen invades and destroys oak trees so rapidly. Studies were undertaken to determine the route of parasitic invasion within infected oak trees, the mechanism of wilting, the influence of environmental conditions on development of the parasite, and means of preventing spread of the disease in State parks and forests of Iowa.

The fungus was found to overwinter commonly in white and bur oak trees, in stumps of diseased trees that had been removed, and occasionally in red oak trees that were infected late in the season.

The disease spreads in a pattern not typical of windblown spore or insect dissemination. *C. quercina* usually spreads from an infection locus to the nearest healthy trees.

Data on destruction of species of oak showed much greater losses in trees of the red oak group than in trees of the white oak group. No difference was observed in the incidence of infection of different sizes of trees.

No host specificity was observed in cross-inoculation tests with isolates from different species of oaks.

C. quercina was isolated from all parts of diseased trees except the acorn.

Isolates of *C. quercina* grew well over a range from 16° to 28° C. with most rapid growth at 22° to 26° C.

Eradication experiments showed that the pathogen could be removed from an area by extreme sanitary measures. Incidence of infection was reduced by removal of the diseased trees from areas of infection. (Phytopath. 39(6): 425-441). For first report of oak wilt in Indiana, see Table 1. Distribution of oak wilt in nine counties in Missouri was reported by T. W. Bretz. (PDR 33 (11): 437-438). The known distribution of oak wilt in the United States at the end of the year is shown on a map (PDR 34(3): 80) compiled in the Division of Forest Pathology; also the occurrence of the disease in Illinois and Minnesota is summarized. The organism is becoming more widespread. (PDR 34(3): 81-82).

QUERCUS VIRGINIANA. LIVE OAK: "The dying of live oaks in certain areas of Texas has become a serious problem for home owners and ranchmen. Both large and small trees die at different seasons and under a wide variety of environmental conditions. As yet, no causal agent has been identified with this trouble, which is presumed to be some sort of disease. Timely, severe pruning of all large branches at the first appearance of the trouble has resulted in apparent recovery and renewed growth from the main trunk of the tree." (Dunlap and Harrison Phytopath. 39(6): 495. Abstr.).

RHUS TYPHINA. STAGHORN SUMAC: *Alternaria tenuis*, leaf spot, see Table 1.

R. TYPHINA. STAGHORN SUMAC: Fusarium oxysporum f. rhois, Fusarium wilt. During the summer of 1946, according to E. Richard Toole, patches of wilting and dead staghorn sumac were found along the Blue Ridge Parkway, Virginia. Sumac clumps were affected in an area of about 5 acres. In 1947, many more sumac plants were found affected in the original area, and scattered affected shrubs were observed up to about 3 miles north and 7 miles south from this point. In the fall of 1948, Hepting observed staghorn sumac plants with wilt symptoms in New Haven, Connecticut. Typical cultures of F. oxysporum f. rhois were isolated. This disease has not been reported from any other localities to date or any other species of Rhus. The symptoms and etiology of Fusarium wilt of staghorn sumac are described. (Phytopath. 39(9): 754-759).

ULMUS SPP. ELM: Ceratostomella ulmi, Dutch elm disease. Propagation of disease-resistant elms will be greatly expedited by the leaf bud cutting technique described by T. W. Bretz. (PDR 33(11): 434-436).

Phytophthora inflata sp. nov., pit canker. Nestor E. Caroselli and C. M. Tucker reported the American elm (U. americana) is the most susceptible species but the disease has been found on slippery elm (U. fulva). The disease has been known for over forty years but its cause has heretofore been undetermined. It occurs widely distributed in New York, Pennsylvania, Connecticut, and Massachusetts. (Phytopath. 39(6): 481-488).

DISEASES OF VEGETABLE CROPS

Philip J. Leyendecker reported a number of unrecorded or unusual plant diseases that occurred in New Mexico during the growing season of 1949. (PDR 34(2); 39-40).

The sclerotiniose disease caused by Sclerotinia sclerotiorum, of various vegetable crops, according to W. D. Moore, has become of increasing importance to growers in many sections of the United States during recent years, causing losses both in the field and during transit to market. While the disease is widely distributed over the country, he points out that one of the most heavily infected areas at this time is in south Florida, where since 1938 it has appeared in practically all of the vegetable growing areas of the lower part of the peninsula and has become a factor in the production of several crops. Attempts to control this disease have been limited to one or two crops and to fairly restricted conditions of culture. One of the most comprehensive attacks on the problem was by Brooks who showed that a combination of flooding and soil treatment with cyanamid would kill a large percentage of the sclerotia in muck soils. His flooding work has suggested a method of control that may be adapted to many areas of Florida and other States where ample supplies of water are available. A series of experiments were conducted in south Florida, the results of which Moore presented (Phytopath. 39(11): 920-927). When flooded in marl, muck, or sandy soils, sclerotia of Sclerotinia sclerotiorum decayed completely within 23 to 45 days. Decay was equally rapid during periods of flooding regardless of depth of burial in soil. Sclerotial decay was as rapid when alternately flooded and drained at intervals of three days as when flooded continuously. The addition of green organic matter to the soil surface did not hasten rates of sclerotial decay during period of flooding. Sclerotia decayed during field flooding at approximately the same rate as under laboratory conditions. In commercial fields sclerotia decayed slowly and incompletely when subjected only to prevailing rainfall in nonflooded fields.

ALLIUM CEPA. ONION: Urocystis cepulae, smut, see Table 1.

ALLIUM ASCALONICUM. SHALLOT: Peronospora destructor, onion mildew. According to E. C. Tims, the earliest development of onion mildew on record in Louisiana was found on shallot in Terrebonne Parish January 24, 1949. The unusually mild weather during the entire first three weeks of January, combined with much moisture in the form of rain, fog and heavy dews, made conditions ideal for early mildew development. This year the early appearance of mildew is more remarkable because of the fact that the disease was not observed at all during the spring of 1948. (PDR 33(3): 166).

APIUM GRAVEOLENS. CELERY: Erwinia carotovora, heart rot of celery was discussed by R. C. Rose as being affected by the weather in Minnesota during the summer. Unusual amounts of the disease occurred. (PDR 33(10): 386-387).

BETA VULGARIS. BEET: Peronospora schachtii, downy mildew. Chupp and Alvarez-Garcia reported that one of the New York beet growers brought beet seed grown in California.

He complained that his greenhouse crop of beets was almost destroyed by some disease, which was concluded to be P. schachtii. The disease has never been reported in New York State as present in the field. (PDR 33(7): 301).

BRASSICA OLERACEA VAR. BOTRYTIS. CAULIFLOWER: see under B. O. var. CAPITATA.

BRASSICA OLERACEA VAR. CAPITATA. CABBAGE: Alternaria oleracea, Alternaria leaf spot, is one of the most destructive diseases of cabbage and cauliflower in Florida, according to Eddins and Burrell. It develops rapidly during warm, rainy weather and causes damping-off of seedlings, a wire-stem and cankers on stems of seedlings; and a spotting of leaves and heads of older plants. Several fields were abandoned before cutting as a result of head spotting. (PDR 33(8): 322-324).

Fusarium oxysporum f. conglutinans, yellows. Eddins and Burrell described a severe outbreak of cabbage yellows in the Florida Hastings area. The disease had not been noted in this section prior to November 1948. No reports of yellows in cabbage fields outside of the Hastings section had been received during the 1948-49 season. It was found at Hastings in 27 fields comprising approximately 313 acres. It destroyed 50 to 90 percent of the crop in 30 acres, 10 to 30 percent in 78 acres and 2 to 5 percent in 108 acres; a trace was seen in 97 acres. The disease was introduced into the Hastings section with affected seedling plants grown in yellows-sick soil in other States. (PDR 33(7): 249-251). Yellows was also found in Louisiana, see Table 1.

Peronospora parasitica, downy mildew, killed all plants in three seedbeds totaling ten acres and caused great damage in others in the Hastings and Sanford areas of Florida. Head spotting was common in all cabbage fields. This disease and Alternaria leaf spot caused greater losses during the 1948-49 season than all other cabbage diseases combined. (PDR 33(8): 322-324).

Sclerotinia sclerotiorum, watery rot, was observed on cabbage seedlings in several plant beds at Hastings, Florida. Five to ten percent of the plants drawn from one affected bed were killed by the disease soon after they were transplanted to fields totaling 100 acres. The disease was present in all maturing crops of cabbage and cauliflower but extensive damage was limited to a few fields. (PDR 33(8): 322-324).

D. M. MacLean reported on the progress of the experimental application of dusts and sprays to cabbage seed plants for control of Sclerotinia sclerotiorum, stalk rot, in Washington. It was felt that control might be obtained by proper timing of spray applications, with plants spaced to enable a thorough coverage with fungicides. (PDR 34(3): 78-79).

Xanthomonas campestris, black rot. Eddins and Burrell reported that black rot was generally distributed in cabbage fields in the Hastings and Sanford areas of Florida. Observations indicated that imported black rot-infected plants, infested seedbed soil, and diseased seed were the principal sources of the disease in the 1948-1949 season. (PDR 33(8): 322-324).

CRUCIFERS. BRUSSELS SPROUTS, CABBAGE, CAULIFLOWER, ETC.: Phoma lingam, black leg, has been found to be an important root parasite of some cultivated cruciferous crops in three counties of California. Because aerial infections of cultivated crops have not been found, survival of the fungus appears to depend on subterranean parts of crucifers that are continuously cropped on the land. The seed produced by diseased cultivated crucifers was found to be uninfected because of the absence of the aerial phase of black leg. (Snyder and Baker, PDR 34(1): 21-22).

CUCURBITS. CUCUMBER, MELON, SQUASH: Cladosporium cucumerinum, scab. Acti-dione was tested for field control of cucumber scab in Michigan, with favorable results reported by Donald J. deZeeuw and John R. Vaughn. (PDR 34(1): 7-8).

Fusarium oxysporum f. niveum, Fusarium wilt, was reported by Weber and others as being the most prevalent and destructive disease on watermelons in the Gainesville area of Florida during the 1949 season. The severity varied from slight traces in new soil and on disease-resistant varieties, to 100 percent infection and 50 percent loss in plantings of common varieties on old cultivated lands, even though they had "laid out" for a decade or more. The dry six-week period previous to June undoubtedly was an exceedingly important factor in the present manifestation of the disease. The lack of rain and resulting higher temperatures were doubly responsible for the excessive prevalence and destructiveness of the disease. (PDR 33(7): 285-286).

Heterodera marioni, root knot. In preliminary tests with numerous chemicals, reported by Tarjan and Moore, seed treatment was ineffective in reducing cucumber seedling infection by the root-knot nematode, or in increasing size and quality of yield. (PDR 33(12): 447-450).

Mycosphaerella citrullina, gummy stem blight, as stated by Weber and others was probably more prevalent on this year's watermelon crop, in the Gainesville area of Florida, than for several years in the past. Regardless of source of seed it was present in almost every field.

On one 100-acre field 100 percent infection was noted. (PDR 33(7): 285-286).

Incidence of cucurbit diseases in South Carolina in 1949 was summarized by Robert Aycock and Morris Hughes. They state that the worst epidemic of cucurbit downy mildew (Pseudoperonospora cubensis) since 1938 occurred this season. Weather conditions were highly favorable for primary infection and secondary spread, so that the cucumber crop was completely killed in two to three weeks. Downy mildew also became serious on cantaloupes. Farmers estimated 60 to 90 percent financial losses. Downy mildew was also a limiting factor in watermelon production. (PDR 33(11): 425-428).

Pseudoperonospora cubensis, downy mildew. Paul R. Miller in his summary on status of the warning service to April 26, stated that in southern Florida downy mildew had been present since the latter part of October. In the Homestead area Yellow Crookneck summer squash planted throughout the winter is commonly affected, and, since downy mildew attacks the maturing crop, no control is practiced. In central Florida the disease was reported in March as being very serious on cucumbers. Later in the month dry weather reduced attack on both cucumbers and watermelon in various parts of the State, (PDR 33(6): 238-243, Fig. 3 shows distribution and severity on the various hosts.)

In the final report by Miller and O'Brien (Supp. 188, page 299) downy mildew of cucurbits was present over the eastern coastline States (Fig. 4 showing distribution). Severe damage was reported in Connecticut, Virginia, Louisiana, South Carolina, Arkansas and Maryland. Reduction in yield was reported as trace or none to 75 percent.

Magnesium deficiency. Charles Chupp and H. John Carew reported a severe spotting of muskmelon foliage in many fields of the muskmelon section of upState New York, which apparently was an abnormal manifestation of magnesium deficiency induced by long-continued hot dry weather. (PDR 33(9): 340).

Virus diseases. Paul D. Keener reported results of surveys to ascertain distribution and prevalence of melon viruses in the Salt River Valley in Arizona. With the exception of late-planted fields, mosaics were less widespread and severe in all melons in 1949 than in 1948. Although there were no general losses in the Salt River Valley from mosaics, several isolated centers of severe infection were noted in cantaloupes and honey dew melons. Curly-top virus was more pronounced and perhaps more significant than mosaics this year in plantings of cantaloupes and honey dews. (PDR 33(11): 429-430). "Cantaloup Mosaic Investigations in the Imperial Valley, 1949" are reported in Supplement 187. This is a continuation of the work reported in Supplement 180. The authors stated that the increasing prevalence of mosaic in muskmelons in the Imperial Valley has been correlated with the increasing area devoted to sugar beets. During the past two seasons the prevalence and rate of spread of mosaic in muskmelons has been correlated with the number of aphids involved in the spring migrations. Tests with numerous insecticides indicated that mosaic cannot be controlled through their application in the fields.

DAUCUS CAROTA. CARROT: Alternaria dauci, blight, was discovered this year causing the first major outbreak in New Mexico, according to Leyendecker. It is believed that the appearance of the disease in epiphytotic form was due to the unusually high amount of rainfall and the high humidity of July and August. Airplane dusting with a number of commercial copper fungicides checked temporarily the damage caused by the pathogen. (PDR 33(11): 431).

Rhizoctonia carotae, crater rot, has occurred in New York carrots since 1934, according to Ramsey and Smith, who reported the disease in epiphytotic form in carrots in Cook County, Illinois. A large Chicago soup company stored about 22 million pounds of these carrots in various cold storages for processing during the winter and spring months (1948-49). The carrots removed from storage toward the latter part of February began to show this decay, and during March the loss varied from 5 to 90 percent with different lots. The most severe loss occurred in top-layer baskets stored in a very humid room. Some baskets of carrots showed 100 percent infection by this organism. The soup company reported that their loss on account of this disease would run well over $100,000. In addition to the total loss of many baskets of carrots, the cost of processing the moderately affected roots was almost doubled. (PDR 33(6): 248-249. 2 Figs.).

IPOMOEA BATATAS. SWEETPOTATO: Mottle necrosis, see Table 1.

LACTUCA SATIVA. LETTUCE: Bremia lactucae, downy mildew. Saul Rich reported that in March of this year, downy mildew severely attacked lettuce seedlings in cold frames. The disease was first observed in the area around New Haven. This outbreak is the first of its kind in Connecticut in approximately 25 years. The attack was brought on by a period of cold, wet weather occurring when the plants were three to four inches high. (PDR 33(5): 233-234).

Big-vein (virus). According to Chupp and Paddock in the spring of 1949 an epidemic of lettuce big-vein virus occurred on light, sandy soil on Long Island, New York, where up to the present incidence has been sporadic and of minor importance. At Kingston, Ulster County 20 percent of the plants were affected, and in Nassau County losses ranged from 10 to nearly 100 percent. Apparently a mild winter followed by periods of unusually high temperatures and rainfall in March and April were responsible for the outbreak. (PDR 33(7): 280-281).

Saul Rich reported that this new lettuce disease is gaining prominence in Connecticut. For the past few years, Connecticut growers of early planted lettuce have sustained serious losses because their crop failed to mature in time for the high priced early market. The plants would do well for a while, but about a month after coming up or being set out they would stop developing and remain at a standstill.

Most growers blamed "unusual weather" for their troubles, until the situation was brought to the attention of the Experiment Station in 1946. Dr. Horsfall diagnosed and proved this disease to be big vein. Research workers have uncovered the following fundamental information about lettuce big vein: (1) The disease is caused by a soil-borne virus which can survive in lettuce-free soil for at least eight years. (2) the disease may be carried by a lettuce root-aphid, but an insect is not required for the plant to pick up the disease from the infected soil. (3) Healthy plants can pick up the disease only through their roots. (4) The severity of symptoms is favored by cool temperatures and excess soil moisture, and infected plants have a good chance for maturing normally when air temperatures are above 60° F. and soil moisture is not excessive. (5) Big vein infected soil can be made safe for lettuce by soil fumigation with formaldehyde or chloropicrin, or by heating with steam to 145° F. for 30 minutes. Other more practical control methods are being worked out. (Conn. Agr. Expt. Sta. Frontiers of Plant Science 2(1): 8, May 1949).

LYCOPERSICON ESCULENTUM. TOMATO: Cladosporium fulvum, leaf mold. F. S. Gooch reported that in a greenhouse at Southwestern Louisiana Institute a crop of tomatoes planted in the fall was severely attacked by leaf mold. (PDR 33(4): 206).

Colletotrichum phomoides, anthracnose. P. A. Young reported that although this disease was found in a few fruits at the Tomato Disease Laboratory near Jacksonville, Texas in 1943, it did not become serious until July 1949. Infection was nearly 10 percent in some cases. (PDR 33 (10): 390).

Rhizoctonia solani, canker. According to Robert A. Conover, in Dade County, Florida, the winter growing season of 1948-1949 was notable for the widespread, and in many cases severe, attacks of R. solani on vegetable crops. Losses of green-wrap tomatoes due to soil rot were unusually high, amounting to as much as 50 percent of certain pickings of experimental plantings. The formation of cankers at the base of tomato branches by this parasite was of particular interest. Since no reference to this symptom has been found in the available literature, he presented a description of it. (Phytopath. 39(11): 950-951).

Stemphylium solani, gray leaf spot. R. W. Samson reported factors associated with severe gray leaf spot on mid-western tomatoes. The disease appeared to have been widespread in Indiana, judging from the canning companies' reports and personal examination of many fields. (PDR 33(10): 387-389).

Internal browning (Marmor tabaci). Francis O. Holmes stated that in outbreaks of internal-browning disease of tomato in Middlesex County, New Jersey, five cases of close association between mosaic plantains and the first affected tomato plants suggested that infection of tomatoes had arisen from this week reservoir. Both the plantains and the tomatoes were found to contain a series of similar but unusual strains of tobacco-mosaic virus. In 1949 on one farm a practical control of internal browning was achieved by locating tomato fields at a distance from all known infected plantains. Environmental conditions also seem to play a part. (Phytopath. 40: 487-492).

Russeting. P. A. Young, in Texas, reported extensive russeting of the stems and dying of the leaves, caused by the tomato russet mite, Phyllocoptes destructor, It occurred in five fields of tomatoes at the Tomato Disease Laboratory near Jacksonville in June 1949. Apparently this is the first report of this serious abnormality in East Texas. (PDR 33(10): 390).

PHASEOLUS VULGARIS. BEAN: Corticium microsclerotia, web blight, was reported by T. J. Nugent as causing considerable damage in Eastern Virginia during August when the temperature favored the growth of the organism. (PDR 33(10): 402).

Jack P. Meiners reported the incidence of bean diseases in southern Idaho in 1949. Dry root rot (Fusarium solani f. phaseoli) was found to be nearly co-extensive with the crop in this region. The disease undoubtedly caused heavy damage. (PDR 34(1): 14).

Sclerotinia sclerotiorum, white mold. B. F. Dana and Edward K. Vaughan reported that various materials were tested for the control of Sclerotinia on beans in Oregon. A brief discussion of the results obtained in 1949 was presented. (PDR 34(1): 8-14).

Uromyces phaseoli typica, rust. L. O. Weaver and C. P. Marcus, Jr. reported a new strain of the bean rust fungus that caused considerable loss to late crops on the Eastern Shore of Maryland. (PDR 33(12): 483-484).

SOLANUM TUBEROSUM. POTATO: Erysiphe cichoracearum, powdery mildew, see Table 1.

Phytophthora infestans, late blight. Reports up to April 26 did not indicate serious damage according to Paul R. Miller. (PDR 33(6): 238-243, appearance and distribution of late blight on potato and tomato are shown on map (Fig. 2). In Florida, decreased prevalence, as compared with the last few years was shown by easier control and moderate to slight loss. The disease was reported on potato in the Lower Rio Grande Valley of Texas and the potato-growing counties of southern Louisiana and southern Alabama. Except for the reports from Florida and one from Indiana, all the records of occurrence on tomato up to April 26 involved seedling transplants shipped from outside sections.

In the final summary by Miller and Muriel O'Brien on late blight of potato and tomato, they reported that the disease was nationally of little economic importance in 1949, although it was reported from numerous places as shown on their maps (PDR Supp. 188: 297-314). The increased use of fungicides for control together with the dry summer probably contributed to the low incidence of the disease.

The five papers read at the New York symposium, sponsored by the Plant Disease Survey on the general subject of "Plant Disease Forecasting" were published in Supplement 190.

Streptomyces scabies, scab. W. J. Hooker and C. E. Peterson reported a strain of the scab organism attacking Cayuga, a previously highly resistant potato variety in Iowa. (PDR 33 (7): 282).

SPINACIA OLERACEA. SPINACH: Peronospora farinosa, downy mildew. C. M. Wright and W. D. Yerkes, Jr. reported observations indicating that this fungus overwinters by means of oospores in the Walla-Walla area of Washington. The disease became so severe during the past three years that growers rely only on a single fall crop. (PDR 34(1): 28).

THE PLANT DISEASE REPORTER

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Division of Mycology and Disease Survey

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UNITED STATES DEPARTMENT OF AGRICULTURE

SUPPLEMENT 195

PLANT PATHOLOGICAL INVESTIGATION IN THE UNITED STATES

II

Supplement 195 September 15, 1950

The Plant Disease Reporter is issued as a service to plant pathologists throughout the United States. It contains reports, summaries, observations, and comments submitted voluntarily by qualified observers. These reports often are in the form of suggestions, queries, and opinions, frequently purely tentative, offered for consideration or discussion rather than as matters of established fact. In accepting and publishing this material the Division of Mycology and Disease Survey serves merely as an informational clearing house. It does not assume responsibility for the subject matter.

PLANT DISEASE REPORTER SUPPLEMENT

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PLANT PATHOLOGICAL INVESTIGATION IN THE UNITED STATES II

Plant Disease Reporter
Supplement 195 September 15, 1950

FOREWORD

Paul R. Miller

The first group of articles on plant disease investigation in the United States was published as Supplement 191. Comment has been very favorable and demand has exhausted our reserve supply. We hope this fact will be a partial recompense to the authors who worked so hard on their contributions.

Articles received since then are presented in this Supplement. Again we wish to thank the contributors for their cooperation in this project.

Others who are considering participation in this series should send us their articles in time for us to publish them before the end of this calendar year. After that time we cannot promise their publication.

CONTENTS

INVESTIGATIONS OF DISEASES OF FRUITS AND VEGETABLES IN TRANSIT, STORAGE AND AT THE MARKET, WITHIN THE UNITED STATES DEPARTMENT OF AGRICULTURE

Harold T. Cook

HISTORY

Since 1930, investigations of the post-harvest diseases of fruits and vegetables have been centered in the Handling, Transportation, Storage and Market Disease Section of the Division of Fruit and Vegetable Crops and Diseases. Previously, they were conducted in various subdivisions of the Department, such as the Office of Pomological Investigations, the Bureau of Markets, and the Office of Cotton, Truck and Forage Crop Disease Investigations.

The headquarters of the present research is located at the Bureau of Plant Industry, Soils, and Agricultural Engineering Station at Beltsville, Maryland. The research is conducted at that station, and at field stations located at Fresno and Pomona, California; Wenatchee, Washington; Harlingen, Texas; Meridian, Mississippi; East Grand Forks, Minnesota; and Orlando, Florida; at market pathology laboratories in Chicago, Illinois, and New York City; at various shipping points; and during shipment, in trains, ships, planes, and trucks.

Interest in the problem of supplying the cities with fresh fruits and vegetables is not new. In the report of the Commissioner of Patents for the year 1861, page 368, Professor L. C. Loomis writes as follows -- "Now it is to be observed that but a small portion of the ordinary supplies of our large cities is in a proper condition when offered in market. The desire of securing the high prices of the earliest products induces the gathering of the first growth while yet unripe, and of that which remains till fully matured the succulent fruits and vegetables commence decay before reaching the termination of the distances large quantities are transported."

In the report of the Commissioner of Agriculture for the year 1869, page 445, a correspondent in California wrote -- "Shipping fruit east has been a failure thus far. This result is owing entirely to want of knowledge on the subject. Most of the fruit shipped has been picked while green, and being poorly packed, has been lost before it reached the eastern markets. There can be no question that our apricots, cherries, pomegranates, pears, and grapes can be placed in New York in good condition and command high prices, but the science of picking and packing must first be understood."

In 1900, Dr. William A. Taylor, who later became Chief of the Bureau of Plant Industry, demonstrated that by means of proper refrigeration it was possible to ship fresh apples and oranges long distances and prolong their market seaason. By this means, he maintained a continuous exhibit of oranges from California and apples from 17 different States at the Paris Exposition (1).

G. Harold Powell, who succeeded Dr. Taylor in charge of the Fruit Transportation and Storage Investigations, studied the actual handling and transportation of carload lots of oranges from California to the eastern markets. His report on these studies in 1908 in a bulletin (124) entitled "The Decay of Oranges While in Transit from California" was an outstanding contribution. As a result of these studies, the chief hazard to the successful marketing of citrus was removed and the long-distance shipment of these fruits became practicable.

About the time that Powell was working on citrus, L. L. Harter made studies of the causes of decay of cabbage in storage and published his results in a circular (71) entitled "The Decay of Cabbage in Storage: Its Cause and Prevention".

In 1915, H. J. Ramsey published a bulletin (144) on his investigations of the effect of careful handling, precooling, and refrigeration in transit on the development of decay in red raspberries shipped from the Puyallup Valley of Washington. This was followed by a preliminary report by F. C. Meier (101) on watermelon stem-end rot in 1917, by a series of papers on strawberry transit diseases by Neil E. Stevens and associates (170, 174, 176) and reports by L. A. Hawkins (80, 81) on his investigations of the cause and prevention of potato leak in 1916 and 1917.

Recognition of the need for special work on market diseases of fruits and vegetables led to the establishment by the Bureau of Markets of market disease laboratories in New York City and Chicago in 1917. Plant Pathologists in these laboratories studied the market diseases, assisted in instructing the inspectors of the newly organized Food Products Inspection Service, and diagnosed plant diseases found in market consignments.

The establishment of the Inspection Service and market disease laboratories gave a great impetus to the study of diseases that affect fruits and vegetables after harvest. In 1919, G. K. K. Link and M. W. Gardner of the Chicago laboratory published a paper (93) in which they reported on the results of the first year's study on market pathology of truck crops. They pointed out

that losses in transit were particularly lamentable because of the value of the time and labor concentrated in the harvested product en route to market. A survey of losses in some of the larger markets of the country showed a minimum loss of $1,250,000 in 1918 to watermelon shipments from four States; loss of hundreds of cars of California grapes from decay caused by Botrytis, Penicillium, and Aspergillus; that 15 to 25 percent losses in Cuban pineapples from Thielaviopsis rot were accepted as a matter of course; and that green vegetables, especially lettuce and beans, usually had to be sorted and reconditioned upon arrival in the markets.

In 1948, Wiant and Bratley (189) published an analysis of over 117,000 inspection certificates issued by Federal Produce Inspectors at New York City between 1935 and 1942. Fourteen different fruits and thirty-one different vegetables were covered by the certificates. The analysis showed that an average of 2.1 percent of all fruit and 3.8 percent of all vegetables were affected by decay or other breakdown.

Soon after the establishment of the market disease laboratories G. K. K. Link and M. W. Gardner published a "Handbook of the Diseases of Vegetables Occurring Under Market, Storage, and Transit Conditions" (92), and D. H. Rose and O. F. Burger published a handbook "Diseases of Fruits Occurring Under Transit, Storage, and Market Conditions" (154). These handbooks were designed primarily to aid the inspectors of the Food Products Inspection Service and their distribution was limited. They were the forerunners of the very popular and useful series of nine U. S. Department of Agriculture Miscellaneous Publications on Market Diseases of Fruits and Vegetables (96, 138, 141, 142, 143, 151, 152, 153, 156) that were published over the period 1932 to 1944 and that are now being revised. This series covered the market diseases of apples, pears, and quinces; citrus and other subtropical fruits; grapes and other small fruits; peaches, plums, cherries and other stone fruits; asparagus, onions, beans, peas, carrots, celery, and related vegetables; beets, endive, escarole, globe artichokes, lettuce, rhubarb, spinach, swiss chard, and sweetpotatoes; crucifers and cucurbits; potatoes; and tomatoes, peppers, and eggplants. They contain numerous illustrations, many in color, of the diseases as they appear in the market.

In 1918, the Bureau of Markets issued a bulletin (35) entitled "Suitable Storage Conditions for Certain Perishable Food Products". In this bulletin directions were given for the proper storage conditions for fruits, vegetables, dairy and poultry products. This bulletin was superseded as far as fresh fruits and vegetables were concerned in 1933 by a circular (160) by Rose, Wright, and Whiteman entitled "The Commercial Storage of Fruits, Vegetables and Florists' Stocks". This publication has gone through several revisions, the last in 1949, and is generally recognized as the standard guide on the storage of fruits and vegetables.

In 1922, the work of the market disease laboratories was transferred to the Bureau of Plant Industry where it could be coordinated better with the other research on storage and transit of fruits and vegetables. However, provision was made for the pathologists of these laboratories to continue to serve as instructors and consultants to the Food Products Inspection Service.

RESEARCH ON POST HARVEST DISEASES OF FRUITS

APPLES AND PEARS: D. H. Rose (146) analyzed the apple inspection certificates for the period November 1917 to July 1921 and found that during the four-year period blue mold occurred more commonly than any other disease. In the boxed apples, scald was second and other decay third in importance, while in the barreled fruit other decay was second and black rot third.

Apple scald, because of its importance in storage and on the market, was the subject of many of the early investigations. The first definite contribution was made by Powell and Fulton (123) in 1903. They found that immature and poorly-colored fruit scalded worse than mature, well-colored fruit, that more scald occurred at 36° F. or higher than at 31° to 32°, and that delays in storing caused more scald. The work of Brooks, Cooley, and Fisher (11, 16, 17) demonstrated the physiological nature of scald and showed that it could be prevented by air circulation and by wrapping the fruit in oiled paper. Further work by the same authors (14, 19) perfected the oiled wraps or shredded oiled paper method of preventing scald to such a degree that it soon came into general commercial use. Recently Schomer and Marth (163) reported that treating fruit with growth-regulating substances reduced the amount of scald.

In 1917, Brooks and Cooley (12) published the results of several years investigations on temperature relations of apple rot fungi. They found that low temperatures had more effect on the growth of fungi on fruit during the initial incubation stages than after the fungus became established. These results showed the importance of promptly and rapidly lowering the temperature of fruit in storage. Haller and Lutz (67) in 1941 reported 50 percent greater decay of apples at 36° than at 32° F. in Potomac River Valley storages.

Fisher (50), in 1925, described the fruit rot stage of the newly described perennial canker disease of apple, and in subsequent papers Fisher (54) and Fisher and Reeves (55) reported on the methods of infection and the importance of rain in dissemination of the organism. Miller (105), in 1932, published on his physiological studies on the perennial canker and anthracnose fungi (Gloeosporium perennans and Neofabraea malicortis) and the rots caused by them.

Brooks and Fisher (20) reported in 1918 that the development of bitter pit and Jonathan spot in storage was influenced by irrigation practices and time of picking.

Rose and Lindegren (158) in 1925 reported on their study of the occurrence of Phytophthora rot as a market disease of pears and apples from several States.

Soft scald and soggy breakdown of apples and pears were the subject of a series of papers beginning in 1920 (18, 22, 61, 62, 63, 66, 68, 69, 70, 106), but no definite control measures have ever been found. The physiological studies and tests on methods of handling, however, have indicated ways in which the disorder may be partially alleviated.

Cooley and Crenshaw (34), in 1931, introduced the use of copper impregnated fruit wraps for the control of gray mold or Botrytis rot of pears. The use of copper-treated wraps is now a general commercial practice and has resulted in important monetary savings.

Extensive studies were made by Bratley (5, 6) on the development of apple scab in storage. He found that scab lesions enlarged in storage and that new lesions resulting from late-season infections may develop during storage on apples that showed no scab when harvested.

When chemical solvents for the removal of spray residue were first employed in the commercial fruit washing operations in the Pacific Northwest, chemical injuries sometimes resulted which were often followed by various kinds of fungus rot. Studies on the effect of the cleaning methods on the keeping quality of apples and pears were conducted, the results of which were published in a series of papers from 1927 to 1931 (38, 39, 52, 53, 56). Information furnished by these investigations made it possible to advise packers how to remove spray residue without injuring the fruit. Recently the use of sodium chlororthophenyl phenol in the wash water for control of various fruit rots has come into commercial use as the result of experimental work by English, Wright, and Smith (44, 48).

Extensive studies have been conducted by English, Smith, Wright, and Ryall on the effect of handling methods and bruises on the development of decay. The results to date have shown that bruises, open lenticels, and washing injuries are the principal courts of infection and that contaminated wash water is an important source of blue mold and other spores (47, 198).

Schomer and McColloch (162) in 1948 reported on the results of their studies on the use of ozone to prevent decay of apples in storage. They found that ozone did not prevent decay or reduce infection of wounds although it did retard the rate of enlargement of infected areas. Fungus colonies on package surfaces were very resistant and were not killed by continuous exposure for 5 months to an atmosphere containing 3.25 p.p.m. of ozone. Fruit was injured and the flavor impaired by the above concentration.

CITRUS: The storage and transportation diseases of citrus fruits have been under investigation since the earliest days of the Bureau of Plant Industry and are being conducted at the present time in Florida, Texas, California, and the market disease laboratories at Chicago and New York.

The early work of Powell (124) on decay of California oranges in transit has already been cited. At about the same time that his work was being conducted with California oranges, similar work by Tenney, Stubenrauch, and others (178, 179) was under way in Florida. These workers found that much of the decay was caused by infection in mechanical injuries from rough handling during the harvesting and packing operations.

Experiments by Fulton and Bowman (58) in Florida and by Barger and Hawkins (3) in California, reported in 1924 and 1925, demonstrated the effectiveness of borax in the wash water for the control of citrus decay. Winston (192) conducted further tests on the borax treatment, the results of which were published in 1935. The results of these investigations form the basis for the borax treatment of citrus that is now used in many packing houses.

Barger cooperated with H. S. Fawcett of the University of California in a study of the relation of temperature to growth of Penicillium italicum and P. digitatum in culture and in the fruit. The results of these tests, which were published in 1927 (49), showed that both fungi grew best and caused more rapid decay at temperatures between 66.8° and 80.6° F. and that P. digitatum was retarded more than P. italicum by higher or lower temperatures.

Fulton and Coblentz (60), in 1929, reported that an estimated 998 out of 1000 spores of Penicillium digatatum were killed by a 45-second exposure to ultraviolet rays. However, holding tests with irradiated oranges showed that the treatment only moderately retarded decay. Failure to obtain better control of infection was attributed to inability of the rays to penetrate much, if any, below the surface and to shading of some of the spores.

Miller, Winston, and Fisher (107) in experiments reported in 1940 demonstrated that oranges

and grapefruits affected with Penicillium digitatum evolve more ethylene than normal fruit. They also obtained positive tests for ethylene with the fungus in pure culture. These results were significant, since they indicated that the presence of decaying fruits in a storage room or container may, by the evolution of ethylene, hasten senescence in other fruits.

Stem-end rot caused by Phomopsis citri and Diplodia natalensis is a very serious post-harvest disease of citrus in Florida, the Gulf Coast States and Texas. Winston, Fulton, and Bowman (195) in 1923 showed that the stem-end rot fungi first gain a foothold somewhere on the stem or button and that disbuttoning would prevent the disease. They showed that the gassing treatment used for degreening the fruit loosened the buttons so that they could be removed easily without damaging the fruit. Winston (193) in 1936 published data showing that pulled grapefruit is less rapidly affected by stem-end rot than clipped grapefruit. He recommended harvesting by pulling, especially for fruit intended for storage or export.

Fulton and Bowman (59) reported in 1927 that the results of six seasons' tests showed that citrus fruit from old trees in Florida kept better if the trees were sprayed once between April 15 and May 5 with 3-3-50 bordeaux mixture. Phomopsis type stem-end rot was reduced by one half or more and Diplodia stem-end rot by a fifth. Blue mold rot was not affected.

During the last ten years a considerable amount of work has been done on developing new chemical treatments for stem-end rot control. Brooks (9) studied various treatments in relation to the ethylene gas degreening treatment. He concluded that borax was the most effective disinfectant, provided it was applied before the ethylene treatment. As an after-ethylene treatment sodium ortho-phenylphenate was more effective. Miller, Winston, and Meckstroth (108) found that treating with a 2 percent solution of sodium ortho-phenylphenate at 110° F. for 2 minutes controlled citrus decay but injured the rind. By adding 1 part by weight of commercial formaldehyde (37%) for 4.5 parts of the fungicide they were able to practically eliminate the injury.

Ryall (65, 161) in cooperative investigations with the Texas Agricultural Experiment Station, tested a number of disinfectants and found that sodium ortho-phenylphenate and sodium metaborate were effective against stem-end rot. They reported further reduction in decay by wrapping the fruit in diphenyl-impregnated tissue wraps and by treatment with nitrogen trichloride gas. Ramsey, Smith, and Heiberg (136) and Heiberg and Ramsey (82) investigated the fungistatic action of diphenyl and found that it was very effective against the stem-end rot and blue and green mold fungi. The material is now becoming rather widely used for impregnating the tissue fruit wraps and box liners.

Childs and Siegler (30, 31, 32), Siegler and Childs (166), Winston (194), and Winston, Meckstroth, Roberts, and Cubbedge (196) have reported on screening tests with hundreds of chemicals for stem-end rot control. A number of chemicals, such as thiourea, have been found to give excellent control of the disease, but have proven toxic in animal tests. A number of other effective materials, such as 2-amino-pyridine, are still being tested for animal toxicity.

Brooks and McColloch (23, 24) in 1936 and 1937 published the results of their investigations of physiological storage diseases of grapefruit and lemons, and in 1946 Harvey (79) published on the relation of Alternaria decay to the physiological condition of lemons as affected by maturity and storage conditions.

CRANBERRIES: The storage diseases of cranberries have been extensively studied by C. L. Shear, N. E. Stevens, and H. F. Bain. This work has been summarized in their bulletin, "Fungous Diseases of the Cultivated Cranberry" (165), which contains an excellent bibliography.

FIGS: Brooks and McColloch (25) studied the spotting of figs on the market and reported that atmospheres containing 23 percent or more carbon dioxide give as good control as immediate storage at 32° F.

GRAPES: Mann (99) studied the handling of California table grapes and in 1929 reported on the importance of careful handling in picking, packing, and shipping grapes to avoid excessive decay, shattering, and raisining. Asbury, Bratley, and Barger (2) in 1940 reported that raisining of California grapes increased up to 10.3 percent during the 10- to 14-day transit period to New York. Most of the increase was due to grapes that were somewhat shriveled or brown in color when shipped.

The use of sulfur dioxide for the control of Botrytis and Penicillium decay of grapes has received considerable attention at the Fresno Station. The results of these studies are presented in a series of papers by W. T. Pentzer, C. E. Asbury, K. C. Hammer, and W. R. Barger (114, 115, 116, 117, 118, 119, 120). The tolerance of different varieties to sulfur dioxide gas and the effect of fumigation on the respiration of the fruit was determined. A method was developed for the slow release of SO_2 within the package. A study was made on the toxicity of SO_2 to Botrytis spores and its effect on infection.

PINEAPPLES: Bratley and Mason (7) in studies with Puerto Rican pineapples demonstrated that much of the decay caused by Ceratostomella paradoxa in transit to New York could be con-

trolled by painting the freshly cut butts with a tincture of benzoic acid at the time of harvesting and packing.

Smith and Ramsey (169) recently reported the occurrence of bacterial fruitlet rot on pineapples that had been shipped by air from Mexico to Chicago. This is the first report of this disease in North America.

STONE FRUITS: Ramsey (145) in 1916 stated that the successful shipment of cherries and fresh prunes is dependent on the elimination of decay in transit and on the market. For the control of decay he recommended proper handling to avoid injuries, orchard sanitation, prompt loading and prompt precooling. These basic principles have been confirmed by further work. Brooks and Fisher (21), in 1921, reported that by means of orchard spraying they reduced brown rot on cherries in transit from 24.3 to 6.4 percent and brown rot on prunes from 28 to 7.1 percent. Brooks and Cooley (13) in the same year reported that prompt cooling resulted in better control of stone fruit rots than was obtained if cooling was delayed for one day. The same authors in 1928 (15) showed that greater infection with brown rot and Rhizopus rot occurred if the fruit was wounded.

Rose (147), in 1924, published a bulletin on "Diseases of Stone Fruits on the Market", and in 1933 Brooks (8) published a circular "Spoilage of Stone Fruits in the Market".

A considerable amount of work has been done by Department workers on the use of carbon dioxide for the storage of stone fruits. Brooks and others (27) showed that carbon dioxide gas was as effective in retarding the softening and decay of certain fruits and vegetables as was precooling them, but that prolonged exposure to atmospheres containing a high percentage of the gas caused objectionable changes in flavor. Brooks, Bratley, and McColloch (10) experimented with short-period carbon dioxide storage for 40 different fruits and vegetables. They obtained favorable results with plums, peaches, Bartlett pears, raspberries, figs, grapefruit, oranges, and sweet cherries. In general, the short-period gas treatment was as effective in retarding decay and maintaining firmness of the fruit as immediate storage at 32° F. and did not impair the flavor. Gerhardt and Ryall (64) controlled fungus decay of sweet cherries for 17 to 20 days in storage at 45° F. with 25 percent carbon dioxide, and the cherries were firmer, brighter, and fresher than those stored in ordinary air at 32°. English and Gerhardt (45), in simulated transportation tests, showed that concentrations within the range encountered in commercial shipments would definitely inhibit brown rot and Penicillium decay. As a result of the above experiments and actual transportation tests the use of carbon dioxide as a supplement to ordinary refrigeration has come into general use by Pacific Coast cherry shippers, and approximately 375,000 pounds of dry ice are used annually for this purpose. The better quality fruit from carbon dioxide treated cars often commands a higher price, amounting in some cases to $300 additional per car.

Ultraviolet light treatment for the control of decay of stone fruits was tested at the Fresno, California, and Wenatchee, Washington, laboratories. English and Gerhardt (46), at Wenatchee, found that although ultraviolet light was toxic to spores it did not control natural decay of cherries even when the period of exposure was up to 25 times longer than the usual commercial treatment. Most spores of Penicillium expansum were killed in 30 seconds but only a few Alternaria spores were destroyed by a 5-minute exposure. They concluded that the failure to obtain control was due partly to the spores becoming lodged in ruptures of the skin where the ultraviolet light could not reach them. Dewey and Pentzer (37) at Fresno also reported failure of ultraviolet light to control decay in peaches, nectarines, and plums. The results obtained with stone fruits were similar to those reported by Fulton and Coblentz (60) with citrus in 1929.

STRAWBERRIES: Rose (149) in 1926 and Stevens (172) in 1932 published an analysis of market diseases of strawberries based on market inspection certificates. Rose reported that during the 7-year period 1919 through 1925 the average percentage of rot for all cars inspected was 5.8, and that 58 percent of the rot was caused by Rhizopus. Stevens reported that the losses during the period 1926 to 1930 showed a decided decrease in both Rhizopus and brown rot. He attributed much of the decrease to improved refrigeration and handling methods.

Stevens (170), Stevens and Wilcox (80, 176), and Stevens and Hawkins (174) published a series of papers in 1917 and 1918 on the nature of the Rhizopus and Botrytis rots and on Rhizopus rots in transit. They stated that the best control of Rhizopus was obtained by careful handling and keeping the berries at a low temperature.

Stevens and Chivers (173) reported that their experimental results indicated that the keeping quality of strawberries was not lowered by picking while wet. They advised against attempting to dry the berries before packing. Stevens (171) had previously reported that strawberries kept better if picked early in the morning while cool even though they were wet.

In 1924 Rose (148) described "leather rot" of strawberries caused by Phytophthora cactorum, and Dodge and Stevens (51) described "hard brown rot" caused by Rhizoctonia solani and "tan rot" caused by Pezizella lythri.

Fisher and Lutz (51), in 1939, reported that in their transportation tests decay increased as the temperatures increased from 40° to 80° F. Rose and Gorman (157) recommended that strawberries be precooled to 40° F. or slightly lower before shipment.

RESEARCH ON POST-HARVEST DISEASES OF VEGETABLES

BEANS: Ramsey (128) investigated the relation of four species of Sclerotinia to decay in beans and other vegetables under transit and market conditions. Harter and Whitney (77), in 1927, reported on nesting in transit caused by Pythium aphanidermatum. They stated that it was very common on beans in transit during the warmer months of the shipping season. Lauritzen, Harter, and Whitney (90) in 1933 published the results of their rather extensive investigations on the effect of environmental factors on the development of diseases that occur in transit. Harter and Zaumeyer (78) discussed the various transit and market diseases of beans in a monograph published in 1944. Brooks and McColloch (26) investigated the cause of spotting and stickiness of shelled green lima beans. They found that the spotting was caused by Cladosporium herbarum and the stickiness was due to various species of bacteria. Washing the pods with a chlorinated lime solution before shelling gave good commercial control.

CARROTS: Meier, Drechsler, and Eddy (102), in 1922, described the black rot disease of carrots, caused by Alternaria radicina, which was responsible for serious losses on the New York market during the winter of 1918-1919. Lauritzen (85) made a further study on the relation of black rot to the storage of carrots in which he determined the method of infection, susceptibility of different varieties, and temperature relations.

Ramsey (127), in 1924, described a new species of Sclerotinia as the cause of decay of carrots on the market.

In 1932, Lauritzen (87) reported on his extensive investigations of storage and transit diseases of carrots, including Sclerotinia soft rot, Rhizopus soft rot, bacterial soft rot, and Botrytis rot.

Ramsey (130), in 1934, reported a Rhizoctonia rot on New York carrots and, in 1949, Ramsey and Smith (140) reported serious losses from this disease on carrots in Chicago storages.

CRUCIFERS: Reference has already been made to Harter's early work on decay of cabbage in storage (71). Ramsey (131) found that stored cabbage is sometimes seriously affected with downy mildew, and Drechsler (42) described a Pythium rot of cabbage on the market. Lauritzen (86) described a Rhizoctonia rot of turnips in storage. He reported that losses could be reduced by storing at a temperature of 0 to 2° C. and 90 percent relative humidity.

CUCURBITS: Reference has already been made to the paper by Meier (101) in 1916 on watermelon stem-end rot. In 1917, Orton (113) described the bluestone and starch paste stem treatment for control of stem-end rot in transit.

Smith and Bryan (167) and Carsner (29) published on the bacterial nature of the angular leaf spot of cucumbers in 1915 and 1918. Meier and Link (103) in 1922 stated that fruit spots caused by this disease could develop in transit following infection during the harvesting and packing operations.

Drechsler (41), in 1925, described the cottony leak of cucumbers, which occurs on cucumbers in the market. In 1940, Wiant and Tucker (191) described a market rot of Winter Queen watermelons caused by Phytophthora capsici.

Wiant (188) made an extensive study of the Mycosphaerella black rot of cucurbits during the period 1938 to 1942, the results of which were published in 1945. In 1937 and 1938, Wiant published two technical bulletins (185, 186) on market and storage diseases of cantaloups and honeydew melons which covered the results of six years' investigations.

Pentzer, Wiant and MacGillivray (121), in 1940, published a comprehensive report of their extensive investigations on market quality and condition of California cantaloups as influenced by maturity, handling, and precooling.

EGGPLANTS: Harter (72), in 1914, described the Phomopsis fruit rot, which is the most common and destructive decay of eggplants found on the market. Drechsler (43), in 1926, described the cottony leak caused by Pythium, which affects eggplant fruit on the market.

GLOBE ARTICHOKE: Link, Ramsey, and Bailey (97), in 1924, published a report on their extensive investigations of the Botrytis rot of globe artichokes, which causes serious losses in transit.

ONIONS: Walker (180, 181), in 1925 and 1926, published the results of his investigations on Botrytis neck rot of onions. He determined the relation of temperature to infection and progress of decay and also showed that desiccation of the neck tissues by artificial curing reduced the losses in storage.

Walker and Tims (182), in 1924, and Link and Bailey (91), in 1925, published on their studies of Fusarium bulb rot of onion, which is important in storage and in transit.

Ramsey and Butler (135) described the injury caused by exposure to ammonia. In 1930, Ramsey (182) published a circular describing the blemishes and discolorations of market onions caused by chemicals, sunlight, and fungi. Ramsey, Heiberg, and Wiant (91) published the results of their studies on Diplodia rot of onions in 1946.

POTATOES: Storage, market, and transit diseases of potatoes have been the subject of extensive investigations by the Bureau of Plant Industry. Orton (111) as early as 1913, and Shapovalov and Link (164), in 1924, published farmers' bulletins on tuber diseases in which they gave directions on proper temperatures in transit and in storage. Reference has already been made to the papers by Hawkins (80, 81) on potato leak.

Orton (112), in 1913, published a paper on the powdery rot of potatoes, in which he warned the growers of the need for care in digging and handling so as to avoid bruising or wounding the potatoes. The results of further investigations on the Fusarium storage rots were published by Carpenter (28), in 1915, Pratt (125), in 1916, and Weiss, Lauritzen, and Brierly (184), in 1923.

Link and Meier (95), in 1922, published a circular on late blight tuber rot in which they discussed the effect of temperature on development of tuber rot in storage and in transit. Cook and Lutz (33) studied the relation of rainfall to time of development of late blight in the field and to the importance of tuber rot in storage at Grand Forks, North Dakota, in 1948. They found that late blight tuber rot is unlikely to be important in storage in seasons when blight occurs early and dry weather prevails during the late part of the growing season and at harvest.

Meier and Link (104), in 1923, published a circular on potato brown rot in which they discussed the development of the disease in storage and methods of controlling it.

Rose and Schomer (159) showed that exposure of the potatoes to heat injury and desiccation made them susceptible to bacterial soft rot. Smith and Ramsey (168) described bacterial lenticel infection, which they said was especially serious on early potatoes grown in wet, heavy soils. Dewey and Barger (36) showed that lenticel infection may also occur in potatoes washed in deep vats as a result of the hydrostatic pressure due to deep submersion forcing the bacteria into the lenticels, and that mechanical injuries are also courts of infection.

Wiant (187), in 1945, published on his investigations of the internal black spot of potatoes. He found that black spot followed mechanical injury to potatoes that had already been submitted to pressure bruising while in storage, and that it was especially apt to develop when the injury occurred while the potatoes were cold.

Wright (197), in 1939, published a very comprehensive bulletin on bruising, freezing, and chemical injuries of potatoes in transit.

Barger, Ramsey, Perry, and MacGillivray (4), in 1942, reported on shipping tests with new potatoes from Kern County, California; and in 1944, Ramsey, Lutz, Werner and Edgar (139) reported on shipping tests with washed early potatoes from Nebraska.

Rose (150), in 1946, published a very comprehensive bulletin on handling and shipping early potatoes. Rose and Cook (155), in 1949, published a review of the literature since 1938 on storage and transit diseases of potatoes.

SWEETPOTATOES: Sweetpotato storage diseases were extensively studied, principally by Harter, Weimer, and Lauritzen. Harter and Weimer (75) summarized the results of these studies in a monograph in 1929. Since this monograph contains an excellent bibliography only a few of the individual papers will be cited here.

Harter and Field (74) published the results of their studies on dry rot caused by Diaporthe batatatis in 1913, and in 1916 Harter (73) published a bulletin on sweetpotato diseases which had a section on storage rots and their control. This was followed in 1918 by a paper by Harter, Weimer and Adams (76) on sweetpotato storage rots.

During the period 1921 through 1926, Harter, Weimer, and Lauritzen published numerous papers on Rhizopus rot, which is the most serious disease of sweetpotatoes in storage. These papers covered a study of the different species of Rhizopus that affect sweetpotatoes, the effect of temperature and humidity on growth and infection, the production of enzymes and the physiology of parasitism. Citations to these papers may be found in the monograph (75) by Harter and Weimer.

In 1935, Lauritzen (88) published a paper on further studies on factors affecting infection and decay by various storage rot fungi.

Lutz (98), in 1945, reported on chilling injury of cured and non-cured Puerto Rico sweetpotatoes.

In cooperative experiments with the Louisiana Agricultural Experiment Station, Martin, Lutz, and Ramsey (100) tested the effectiveness of dip treatments for the control of black rot in transit

on washed sweetpotatoes. Dipping the potatoes in a borax solution gave promising control, but a wax emulsion containing sodium ortho-phenylphenate was not effective. Kushman and Cooley (84) reported in 1949 that subjecting infected sweetpotatoes to 110° F. for one day and then curing at 85° and 80 percent humidity prevented development of black rot in storage.

SPINACH: Wiant, Ivanoff, and Stevenson (190), in 1939, described the white-rust disease, caused by *Albugo occidentalis*, which Wiant found on Texas spinach on the New York market in 1937.

Friedman (57), in 1950, reported that bacterial soft rot is the principal cause of decay in prepackaged spinach. Increased drying by centrifuging reduced decay, but the best control was obtained by refrigeration.

TOMATOES: Tomatoes are especially subject to decay in transit and on the market, and they have, therefore, been the subject of much study. Stevens and Nance (175) analyzed the market inspection certificates issued on tomatoes from five different States and Mexico to determine the diseases that cause spoilage in transit. Diseases listed on the certificates were *Rhizopus* (*Rhizopus nigricans*), *Phoma* (*Phoma destructiva*), bacterial soft rot (*Bacillus carotovorus* and others), soil rot (*Corticium vagum*), blossom end rot (physiological), buckeye (*Phytophthora terrestris*), anthracnose (*Colletotrichum phomoides*), *Alternaria*, *Fusarium*, late blight (*Phytophthora infestans*), and nailhead (*Macrosporium* spp.). *Rhizopus* was the most important, *Phoma* rot was second, and bacterial soft rots were third.

Jamieson (83), in 1915, published the results of investigations showing that *Phoma destructiva* was an active wound parasite on green or ripe tomato fruit. Link and Meier (94) stated in a circular published in 1922 that the fungus does not grow above 90° F. or below 42°. Fruit from infected fields not showing any signs of the disease when packed developed *Phoma* spots in 4 or 5 days in transit or in ripening rooms. Nightingale and Ramsey (109) studied the development of *Phoma* rot in test shipments from Florida. They found that tomatoes that apparently were sound when packed showed *Phoma* lesions on arrival at market and that the lesions enlarged more rapidly as the fruit became riper.

Ramsey and Bailey (133) made field, transit, and storage studies of nailhead spot of Florida tomatoes from 1925 to 1927. Their studies showed that there may be an appreciable increase in number of spots and percentage of infected fruits during transit and storage.

Pritchard and Porte (126), in 1923, described a watery soft rot caused by *Oospora lactis parasitica*. The rot was reduced considerably by washing the fruit with an aqueous solution of chloride of lime (1:40) or formaldehyde (1:240). Ramsey (132), in 1935, described the *Pleospora* rot of tomato that had caused considerable damage to California tomatoes during the three preceding years.

In 1931, Ramsey and Bailey (134) published the results of their studies on late blight rot in transit and at the market. They found that the blight lesions increased 1 to 1 1/2 inches in diameter during six days in transit. They obtained some control by immersing the fruit for two minutes in a formaldehyde solution (1:300).

Nightingale and Ramsey (110), in 1936, published a paper on their extensive studies on the temperature relations of nine different fungi that cause tomato fruit rots. Growth rate in culture, infection, and development of decay were studied.

Porte (122), in 1934, tested various chemical washes and found that the chemical treatments reduced the number of decayed fruits by as much as 29 to 59.5 percent.

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U. S. DEPARTMENT OF AGRICULTURE, DIVISION OF FRUITS AND VEGETABLE CROPS AND DISEASES, BUREAU OF PLANT INDUSTRY, SOILS, AND AGRICULTURAL ENGINEERING

VEGETABLE DISEASE INVESTIGATIONS IN THE UNITED STATES DEPARTMENT OF AGRICULTURE, 1885-1950[1]

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Until the establishment of the Bureau of Plant Industry (now the Bureau of Plant Industry, Soils, and Agricultural Engineering) in 1901, the plant pathological research of the Department of Agriculture was conducted in the Division of Vegetable Physiology and Pathology. There, a small but able staff carried on research on diseases of vegetables, fruits, cotton, cereals, and other crops. One of the earliest accomplishments in vegetable pathology was the isolation (1894) of *Fusarium oxysporum* Schlecht f. *niveum* (E.F.Sm.) Snyder & Hansen, and the demonstration that this soil-borne vascular parasite was the cause of watermelon wilt. This work, which opened the way for later studies of the *Fusarium* wilts of cabbage, tomatoes, and other crops, was accompanied by a prediction that diseases of this type would be of constantly increasing importance.

Work on bacterial diseases of plants was new in the 'nineties and then, as for many later years, the Department's work was outstanding in this field. The organism, *Erwinia trachephila* (E.F.Sm.) Holland, causing bacterial wilt of cucurbits was isolated (1895) and it was shown to be transmitted by the striped and spotted cucumber beetles *Acalymna vittata* F. and *Diabrotica undecimpunctata howardi* Becker, respectively. The organisms causing bacterial wilt of tomatoes and other solanaceous crops, *Pseudomonas solanacearum* E.F.Sm., (1896) and bacterial blight of beans, *Xanthomonas phaseoli* (E.F.Sm.) Dowson, (1898) also were isolated and described. Studies of black rot of cabbage, *Xanthomonas campestris* (Pam.) Dowson, dealt in detail with the mode of infection and progress of the organism in the plant (1903).

Between 1904 and 1911, a wilt-resistant watermelon variety was produced by crossing a resistant but inedible citron with the cultivated melon. Selections of plants with desirable characters were made from a large F_2 population and through further selection a wilt-resistant, edible melon eventually resulted. This variety, Conqueror, never found favor in the markets but it enters into the parentage of several wilt-resistant melons of today. This work is of more than ordinary interest because it was one of the first attempts at synthesis of a variety resistant to a particular disease.

In 1907 the Office of Cotton, Truck, and Forage Crop Disease Investigations was established and its staff was gradually increased until the research included diseases of all the major vegetable crops. Also some work on bacterial diseases of vegetables was done in the Laboratory of Plant Pathology, a separate organization that specialized in bacteriological research. The work of that Office continued until 1928 when it became a part of the newly organized Division of Horticultural Crops and Diseases which, in 1932, took its present name, Division of Fruit and Vegetable Crops and Diseases. This Division was formed in the course of a reorganization in which the plant research was planned primarily around a crop or group of crops, with the combining of pathological and horticultural investigations of vegetables in a single section. This arrangement has led to an increasingly close correlation of the horticultural and pathological research that has given added breadth, balance, and effectiveness to work in both fields. From the start, much of the work on vegetable diseases has of necessity been carried on in sections of the country where the diseases under investigation are most damaging and prevalent. Many of the staff of vegetable pathologists have been and are stationed in the field and work in cooperation with State agricultural experiment stations. Much of the work reported here has been cooperative with one or more States.

In the period from 1900 to 1920, the field of plant diseases was still relatively unexplored and naturally, at first, there was need for more work on the isolation, identification, and description of plant pathogens than generally is the case today. However, the study of the parasite, its life history, and effects on the host are always necessary precursors of the development of control measures, and the need of practical means of control was not forgotten. The use of fungicides, seed disinfection, measures of sanitation, and modification of cultural practices all were beginning to play a large part in disease control. Disease resistance was recognized as the only apparent means for control of many diseases, but progress in this field still was comparatively slow although there was growing emphasis on this type of research.

The first World War brought a need for increased food production and a more general realization of the economic seriousness of vegetable diseases. During 1918-1919, the Office of Cotton,

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[1] The work on vegetable diseases as reported here does not include those of potatoes or those occurring in handling transportation, and storage of vegetable crops. The dates used refer to date of publication of the results described.

Truck, and Forage Crop Diseases maintained extension pathologists in many of the States, where they studied losses from disease and reported the occurrence of many diseases the importance of which had not been fully recognized and some of which were as yet unidentified. This period also marked the beginning of the Plant Disease Survey which helped to clarify and expand the pathologists' conception of the problems of disease incidence and control. As time went on, there was increasing pressure by growers, shippers, and processors of vegetables for more research on disease control, due in part to the increase of intensive production of these crops. As a result, the research on vegetable diseases was broadened and became organized into projects that included beans and peas, cabbage and related crops, celery, cucumbers and melons, lettuce, onions, tomatoes, and sweetpotatoes.

Since 1920 the investigations of vegetable diseases in the Department of Agriculture have undergone progressive changes in the relative emphasis on various types of research. After 1920 there was a rapid realization of the general prevalence of virus diseases on vegetable crops and the actual or potential losses from virus infection. Virus disease research increased in relative importance, and by 1930 was a major field of vegetable pathology.

From 1920 to 1935, the possibility of disease control by measures of sanitation was explored rather thoroughly and the value of eradication of perennial weed hosts of viruses and fungi, destruction of crop refuse, seed bed sanitation and disinfection, and crop rotation received considerable attention. It was found that such measures were of very definite value in control of certain diseases; but even for those there were often practical difficulties in the application by the average grower. As a result, there has been recently less general emphasis on research of this type, except for certain virus diseases.

Up to about 1925, research was fairly extensive on the control of diseases of celery, cucumbers, melons, and tomatoes by the available copper fungicides applied as sprays or dusts. For the next ten years, there was little work of this type, but after 1935 the need for disease control of leaf diseases on seedling tomato plants grown in the South for shipment to the North and the problems of control of powdery mildew, rust, and sclerotiniose of beans led to further research with fungicides, particularly the newer organic compounds.

The most marked trend in the work on vegetable diseases has been the increasing effort toward the development of varieties resistant to disease. This has been due partly to the realization that many virus diseases can be adequately controlled only through disease resistance. Many of the most damaging diseases of vegetables are caused by soil-borne fungi, and here again the only feasible means of control under our current cropping practices has been the production of resistant varieties. A number of leaf spot diseases can be checked by the use of fungicides, but even with the newer materials control is not entirely effective when climatic conditions are favorable to disease, and there is always the likelihood of lack of control because of faulty timing or inadequate methods of application by the grower.

In the Division of Fruit and Vegetable Crops and Diseases, the emphasis in the last 15 years has been toward research problems of regional rather than local importance and particularly those which are likely to require long-time research for their solution. At present, much of the vegetable disease research involves the search for and use of disease resistance.

In describing the investigations of vegetable diseases in the Department of Agriculture during the past fifty years it is impracticable to mention all of the research that has contributed to their progress. However, the account has been made sufficiently inclusive to give a fairly broad conception of the research in vegetable pathology. In order to view the work as a whole it has seemed best to discuss it on the basis of the major types of investigations involved rather than from the standpoint of research on individual crops. Therefore, the investigations have been grouped into three classes:

(1) Pathological research that includes descriptive mycology, studies of pathological history, variability of pathogens, modes of overwintering of fungi, bacteria, and viruses, effects of environment on infection and disease development, and the effects of nutrition on disease expression.

(2) Control by means other than disease resistance, including the use of fungicides, seed treatments, sanitation, and certain other methods of control.

(3) Development of varieties resistant to disease and research on the nature and inheritance of resistance.

PATHOLOGICAL INVESTIGATIONS

DESCRIPTIVE MYCOLOGY -- The identification and description of fungi and bacteria causing plant diseases has been part of the work done by pathologists throughout the country in laying the foundation for future work on disease control. The task has required careful field observations, accurate mycological study, a knowledge of the host plants and their anatomy, and the development

of new techniques of isolation, culture, and inoculation that today are the common tools of the pathologist. In the course of about 55 years, pathologists in the Department of Agriculture have been the first to describe many of the fungi and bacteria causing disease in vegetables. Among these diseases are the following, listed by crops:

Bean: Bacterial blight (Xanthomonas phaseoli), bacterial wilt (Corynebacterium flaccumfaciens (Hedges) Dowson), anthracnose of lima bean (Colletotrichum truncatum Andrus & Moore).
Cabbage and related crops: Cauliflower leaf spot (Pseudomonas maculicola (McCul.) F. L. Stevens).
Cucurbit crops: Bacterial wilt (Erwinia tracheiphila (E. F. Sm.) Holland), bacterial leaf spot of cucumber (Pseudomonas lachrymans (E. F. Sm. & Bryan) Dowson), leaf spot of squash (Xanthomonas cucurbitae (Bryan) Dowson), cucumber leaf spot (Stemphylium cucurbitacearum Osner), cottony leak of cucumbers (Pythium aphanidermatum Drechsler), watermelon wilt (Fusarium oxysporum f. niveum, blossom end rot of watermelon (Pythium acanthicum Drechsler).
Eggplant: Fruit rot (Phomopsis vexans (Sacc. & Syd.) Harter).
Lettuce: Bacterial wilt (Xanthomonas vitians (N. A. Brown) Starr & Weiss), bacterial wilt (Pseudomonas viridilivida (N. A. Brown) Holland).
Onion: Neck rot (Botrytis byssoidea Walker and M. squamosa Walker).
Pea: Root rot (Aphanomyces euteiches Drechsler).
Rhubarb: Foot-rot (Phytophthora parasitica var. rhei Godfrey).
Sweetpotato: Foot-rot (Plenodomus destruens Harter), dry rot (Diaporthe batatatis Harter and Field), mottle necrosis (Pythium spp.).
Tomato: Bacterial wilt (Pseudomonas solanacearum), bacterial canker (Corynebacterium michiganense (E. F. Sm.) H. L. Jensen), bacterial speck (Pseudomonas punctilans (Bryan Dows.), fruit rot (Isaria clonostachoides Pritchard & Porte).

Other mycological and descriptive work has included studies of a number of species of Pythium, Phytophthora, and Aphanomyces causing roots rots of peas, beans, lettuce, celery, spinach, and other crops. There also have been extensive investigations of fungi parasitic on nematodes and of predaceous fungi that capture nematodes, spring tails, amoebae, rotifers, and other animalcules found in the soil.

In the above list, 23 of the 25 diseases mentioned were described prior to 1926, while 17 of the 18 known virus diseases described by Department pathologists (see section on plant viruses) were reported after that date. While the difference would be expected in view of the fact that the field of fungus and bacterial parasites had been quite thoroughly explored by 1925 when the work on viruses had really just begun, it still is a reminder of one of the changes that have occurred in the predominant types of pathological investigations.

In addition to diseases caused by fungi, bacteria, and viruses, descriptions also have been made of diseases due to other causes or of unknown cause, which include:

Non-parasitic diseases: Celery blackheart due to excess soil moisture, and bald head of beans caused by threshing injury.
Diseases of unknown cause: Brown blight of lettuce, ghost spot of tomatoes (possibly due to insect puncture), and phyllody of beans (possibly related to tomato big bud).

PATHOLOGICAL HISTOLOGY -- Research in the pathological histology of invasion of the host by plant pathogens often has been a necessary part of the investigations of diseases caused by fungi and bacteria.

In club root of cabbage, Plasmoidophora brassicae Wor., it was shown (1918) (1934) that the young plasmodia migrate by direct penetration of the cells and also by dividing with the host cell in its division. The most rapid advance of the parasite was found in the cambium of the root and hypocotyl. A migration up and down the cambium from the infection point accounts for the spindle formation of the clubbed roots. In stems the host response is chiefly in the cortex and galls of spheroid shape are formed.

Studies were made of the pathological histology of bacterial blight of bean (1930) in which it was found that the organism invades stomata and wounds, penetrates intercellularly, and eventually enters the xylem tubes where it can break through thin portions of the xylem and invade the parenchyma. The seeds are invaded from the pod cavity through the micropyle or by way of xylem

strands through the funiculus.

Comparative studies also were made of invasion of beans by the organisms causing bacterial wilt, bacterial blight, and halo blight, (Pseudomonas phaseolicola (Burkh.) Dowson) (1931). It was shown that the wilt organism is chiefly a vascular parasite and does not infect through the stomata, as do the others which fill the stomatal cavities and produce spots with a watersoaked appearance.

In investigation of bacterial canker of tomatoes (1928) it was demonstrated that the organism could enter the vascular bundles of the fruit and penetrate the fleshy outer coat of the seed, where it remained viable and caused cotyledonary infection. In the case of fruit infection of tomatoes by the nailhead rust fungus, Alternaria tomato (Cke.) Weber, it was found (1920) that the resistance of the fruit to invasion becomes greater with age and is correlated with the increased resistance of the cuticle to puncture.

When sweetpotatoes are infected by the black rot fungus, Endoconidiophora fimbriata (Ell. & Halst.) Davidson, it was found (1921) that after the hyphae had penetrated a short distance below the surface of the tuber a layer of cork cambium four to six cells deep was formed beneath the invaded tissue. It was felt, though not proven, that this cork formation may account in part for the lack of any deep penetration of the tissues by this fungus.

VARIABILITY OF PATHOGENS -- Studies of possible variations in pathogenicity of parasitic fungi have been of particular importance in relation to the development of disease resistant plants. In the case of cabbage yellows (Fusarium oxysporum Schlecht. f. conglutinans (Wr.) Snyder & Hansen), it was found (1934) that numerous collections of the fungus from widely separated localities were quite uniform in pathogenicity.

Similar work (1940) with the fungus causing wilt of tomatoes (Fusarium oxysporum Schlecht. f. lycopersici (Sacc.) Snyder & Hansen), showed a definite range of pathogenicity and cultural characteristics in the many isolates tested, and considerable saltation within individual monoconidial isolates. However, while certain strains showed especially high virulence, there was no marked difference in host selectivity with respect to resistant and susceptible varieties. A study (1942) also was made of the pH relation of varying strains of the fungus in culture and of the comparative toxic effects on the plant of extracts from mild and virulent forms of the fungus (1943).

Investigation of bean rust (Uromyces phaseoli var. typica Arth.), in 1935, demonstrated the existence of 2 physiologic races of the fungus, and by 1948 24 races from the United States and Hawaii had been identified by the use of 7 differential hosts. The degree of susceptibility to 14 of these races was determined for a large number of bean varieties.

In the case of powdery mildew of cantaloup, (Erysiphe cichoracearum DC.), it was found (1938) that two races of the fungus were present in the cantaloup-growing sections of the West. The second race, which may represent a mutation or an introduction, has proved of great importance from the standpoint of disease resistance, as will be shown elsewhere.

MODES OF OVERWINTERING OF FUNGI, BACTERIA, AND VIRUSES -- There have been extensive investigations of the life histories of various fungi and bacteria and of the means of overwintering of viruses, because of the evident importance of overwintering in relation to the spread and control of disease.

Transmission of plant pathogens on or in the seed has been demonstrated in the case of such diseases as bacterial blight of bean (1897), bacterial wilt of bean (1926), cucumber angular leaf spot and anthracnose (Colletotrichum lagenarium (Pass.) Ell. & Halst.) (1918), black-rot and black-leg (Phoma lingam (Fr.) Desm.) of cabbage and related crops (1922-24), Phomopsis fruit rot of eggplant (1914), and bacterial canker of tomato (1928). In the last case the organism was found to live for some years in seed (1942). In sweetpotatoes it was found (1913-16) that infection commonly occurs in plants produced from "seed stock" infected with stem rot, (Fusarium oxysporum Schlecht. f. batatas (Wr.) Snyder & Hansen), foot-rot, scurf (Monilochaetes infuscans Halst.), black-rot, and certain other diseases.

It was demonstrated (1920) that the virus of cucumber mosaic may possibly be seed-transmitted, but this is so rare as to be of no importance in control. However, about 10 percent of seeds from the mosaic plants of common wild cucumber (Micrampelis lobata) produced mosaic plants. It has been shown that seed freshly extracted from tomato fruits infected with common tobacco mosaic (Marmor tabaci Holmes) and the leaf-withering strain of this virus (var. siccans) will produce 1 to 3 percent of mosaic seedlings; but when the same seed is aged for 30 days or more, no seed transmission occurs although the virus can be readily recovered from the seed coat (1939, 1942).

The overwintering of plant pathogens in the soil has been a phase of the research on many vegetable diseases and only those will be mentioned where overwintering in the soil was demonstrated for the first time or the findings are of some special significance. Such investigations include cabbage black-leg and black-rot (1922), angular leaf spot and anthracnose of cucumber (1918), bacterial canker of tomato (1942), Phomopsis of eggplant (1914), brown blight of lettuce (1931), big vein (virus) of lettuce (1934), onion smudge (1921), onion neck rot (1925), sweetpotato foot-root (1913), sweetpotato scurf (1916), sweetpotato mottle necrosis (1923). All of the pathogens causing these diseases were found to persist for at least one year on crop debris in the soil and many of them for much longer periods. Big vein is of especial interest since it is one of the few plant viruses that persist for any extended period in the soil. In addition to the above it has been shown that the viruses of ordinary tomato mosaic (M. tabaci) and single-virus streak (M. tabaci var. canadense Holmes) (1930) may remain active for three months in greenhouse soils though they were not found to overwinter to any appreciable extent in the field. It has also been shown (1942) that the organism causing bacterial wilt of tomatoes overwinters as far north as New Jersey.

The overwintering of viruses on perennial weed hosts was demonstrated in 1925 in research on ordinary cucumber mosaic (Marmor cucumeris). This virus was found on milkweed (Asclepias syriaca L.), pokeweed (Phytolacca decandra L.), and wild ground-cherries (Physalis spp.), and it was demonstrated that it could be carried to the cultivated hosts by aphid vectors. The infected weed hosts were found exclusively near fields that at some time had grown cucurbit crops or in the vicinity of home gardens. This last fact served to explain the greater occurrence of the disease in cucumber fields near towns and villages than in those at a distance in the country. Later work with the southern celery strain (var. commelinae) of cucumber mosaic virus in Florida showed that it was extremely prevalent on a monocotyledonous host, Commelina nudiflora, which occurred along ditch banks and in other moist places throughout the celery-growing area. In these investigations it was also shown that a number of other perennials, both wild and cultivated, were subject to infection by the virus.

It has also been found that the cabbage mosaic complex (see section on virus diseases) overwinters on certain cruciferous hosts, such as shepherd's purse (Capsella bursa-pastoris) and penny cress (Thlaspi arvense), and on cabbage seed plants.

An unusual case of the overwintering of a bacterial pathogen in insects was discovered in the course of investigations of bacterial wilt of cucumber (1920), which showed that the causal bacteria are to be found in the intestinal tract of the two species of cucumber beetles that disseminate the disease. Evidence indicated that the bacteria also overwinter in the bodies of hibernating adult beetles. Since the organism is not carried in the seed or soil the insects seemingly are the only means of its overwintering. In 1921 beetles emerging from hibernation abnormally early in the spring in Wisconsin produced wilt infection on caged plants in the greenhouse, a fact that seemingly confirms the likelihood of this means of overwintering.

VIRUS DISEASE INVESTIGATIONS- - The work on virus diseases in the Department of Agriculture has included viruses affecting bean, cabbage and cauliflower, celery, cucumbers and melons, lettuce, tomatoes, and sweetpotatoes. This work has involved identification of new viruses and studies of others already described. In addition to certain work on overwintering of viruses and the effect of environment on disease expression, the investigations have also dealt with many other phases of virus reasearch.

Legume Viruses: Research on viruses of beans and peas has resulted in the identification of a number of new viruses, chiefly those of beans. Lima bean mosaic, described in 1938, was found to be caused by a strain of cucumber mosaic (Marmor cucumeris var. phaseoli Holmes). Southern bean mosaic (bean virus 4, M. laesiofaciens Zaumeyer & Harter), described in 1943, was found to have a thermal inactivation point of 90° C, which is much above that of most viruses. On certain varieties this virus produces systemic symptoms and on others only a necrotic spotting of the inoculated leaves. A disease known as greasy pod of beans was found (1947) to be caused by a virus that may be a strain of common bean mosaic (M. phaseoli Holmes). This virus produces the symptoms known as "black-root" in varieties where resistance to common mosaic stems from Corbett Refugee, Kentucky Wonder, and Creaseback types. These symptoms were not produced in resistant varieties derived from strains of U. I. Great Northern No. 1 or Robust. Pod mottle of beans (M. valvolarum Zaumeyer & Thomas), which causes systemic symptoms somewhat similar to but more intense than those of southern mosaic, was reported in 1948. Local lesions of this virus differ from those of any other virus reported on beans. All varieties tested were susceptible either to systemic or to local infection. Red node of beans was found (1949) to be caused by a strain of tobacco streak virus (M. orae Holmes), and a virus known as yellow stipple was discovered, which causes a mild mottle on snap beans but in most field varie-

ties produces small, yellow necrotic spots. Studies also were made (1935) of the relation of other legume mosaics to bean.

In 1925 a mosaic of garden pea transmissible to sweetpea and red clover (Marmor leguminosarum Holmes) was described. Later (1938) pea streak caused by M. trifolii Holmes was reported. Three other mosaic diseases of pea were described (1940) as caused by pea mosaic virus 4, by pea mosaic virus 5 (M. fastidiens Holmes), and by alfalfa mosaic virus 2. It was also shown (1936) that mosaic viruses of white clover, red clover, white sweetclover, and alsike clover were transmissible to pea.

Crucifer Viruses: In 1921 a mosaic (Marmor brassicae Holmes) was described on Chinese cabbage, mustard, and turnip, but no further work was done on this disease at the time.

Cabbage mosaic, which has caused serious damage to this crop in the Middle West and in the seed-growing sections of the Pacific Northwest, was shown (1945) to be caused by a combined infection of the plants with a strain of the cabbage black ring virus (Marmor cruciferarum Holmes) of California and a strain of the cauliflower mosaic virus of California (M. brassicae Holmes). It also was shown that ring necrosis of cabbage is caused by the black ring virus. Host range and field studies have shown that the mosaic viruses, which are transmitted by aphids, overwinter chiefly on cabbage seed plants or on cruciferous weeds such as shepherds-purse (Capsella bursa-pastoris (L.) Medic.) and pennycress (Thlaspi arvense L.).

Cucumber Mosaic Virus: Cucumber mosaic caused by Marmor cucumeris Holmes was studied extensively (1918-1925), with particular reference to virus host range and overwintering. This virus was one of the first whose hosts were found to extend over a wide range of plant genera. It was also found transmissible to many cucurbit hosts, including squash, pumpkin, and muskmelon, but not watermelon. These studies resulted in one of the earliest demonstrations of the fact that perennial weeds may act as reservoirs of the virus for primary infections of cultivated crops. (See section on overwintering of plant pathogens, above). Later work (1928) showed that an aphid vector (Aphis gossypii Glover) can transmit the virus after a brief feeding on a mosaic plant but did not continue to carry it after the first feeding period. It was later found (1930) that a serious disease of celery in Florida known as brown-stem was due to a virus whose common wild host was a perennial monocotyledonous weed, Commelina nudiflora L.. This was the first example of the transmission of a virus from a monocotyledonous to a dicotyledonous host. Later studies (1934-35) indicated that this southern celery mosaic virus was similar to but not identical with ordinary cucumber mosaic, and later work by others supported the belief that it was a strain of this virus, M. cucumeris var. commelinae Holmes). Studies of the host range (1936) showed that 93 species in 23 genera apparently were susceptible to infection by artificial inoculation or by aphids. Forty-six of these species were found naturally infected.

Virus Diseases of Lettuce: Lettuce mosaic (Marmor lactucae Holmes) was described in 1921 and shown to be transmissible by aphids.

Big vein of lettuce was reported in 1923 and it was demonstrated that it could overwinter for some years in the soil, but no cause was found for the disease although it was shown that it could be destroyed by steam sterilization of the soil. In 1944 limited experiments in cooperation with the Bureau of Entomology and Plant Quarantine indicated the possibility of transmission by a root aphid (Pemphigus lactucae Fitch.) but no definite conclusions could be drawn. In 1945 it was found that the disease is transmissible by inoculations of roots or leaves with juices of the roots of diseased plants but no infection was obtained by inoculations with leaf juices. Other experiments (1945) indicated a possibility that fresh leaf tissue from diseased plants might cause infection if placed in contact with the roots. No evidence of seed transmission was obtained but it was found that the virus could persist for 8 years in the soil.

Tomato Virus Diseases: Investigations of virus diseases of tomatoes have included (1928) studies of the effect of air and soil temperature on the development of double virus streak caused by a combined infection with ordinary tobacco mosaic (Marmor tabaci) and the X-virus of potato (Annulus dubius Holmes var. vulgaris Holmes). Tomato mosaic was found to live for 90 days in greenhouse soils (1928), as also the strain causing single-virus streak, but no evidence of overwintering in the field was secured. Seed tramsmission (see section on overwintering) was demonstrated (1937) in the case of seed freshly extracted from mosaic-infected fruits. A disease caused by combined infection of greenhouse plants with the viruses of cucumber and tobacco mosaic was described (1939). In 1942 a report was made of a leaf-withering strain of tobacco mosaic (M. tabaci var. siccans Doolittle & Beecher), which causes severe defoliation of tomatoes. Studies with the virus of tomato curly top (Ruga verrucosans Carsner & Bennett) in Utah and Oregon dealt chiefly with the effect of light, temperature, nutrition, and other factors on symptom expression and are discussed in the section dealing with environment in relation to disease. Big bud (Chlorogenus australiensis Holmes) of tomatoes was reported from Oregon (1942) and shown

to be transmissible by grafting.

Virus and Virus-like Diseases of Sweetpotato: A so-called mosaic of sweetpotatoes was studied (1928), but no evidence was found that it was transmissible by mechanical inoculation or grafting, and it was felt that it was not caused by a virus. A virus disease known as feathery mottle was found (1946) to be transmissible only by grafting, although it produces symptoms similar to those of the mosaic group of viruses. It apparently is rare and has been described as Flavimacula ipomeae Doolittle & Harter.

EFFECTS OF ENVIRONMENT ON DISEASE EXPRESSION AND DEVELOPMENT -- The relation of environment to disease has been extensively investigated in the course of research on fungous, bacterial, and physiologic diseases and to some extent with certain plant viruses. The work has dealt with the effects of air and soil temperature, soil moisture, soil acidity, nutrient chemicals, and light, in relation to the growth of fungous and bacterial pathogens in culture and to the occurrence of infection and the development of disease in the host. The examples of such work discussed here are only illustrative and do not include a number of other similar investigations by workers in the Department of Agriculture.

Temperature: In cabbage yellows the fungus is most destructive at temperatures of about 26° C., and soil temperature is the most common limiting factor in disease development. It was found (1930) that cabbage seedlings having an homozygous resistance (Type A) governed by a single dominant gene were not affected at temperatures of 26° C., whereas plants carrying a genetically more complex and incomplete resistance (Type B) are badly injured at the same temperature (1934, 1937). This fact has proved a most valuable criterion for selecting seedlings when breeding for resistance.

At constant soil temperatures the infection of tomato plants with the organism causing bacterial wilt was sharply checked at 60° F., while at temperatures of 70° or above there was a progressive increase in the rapidity and severity of disease development. With bacterial canker of tomato soil and air temperatures of 27° to 28° C. were found most conducive to severe development of the disease.

The fungus causing downy mildew of lettuce (Bremia lactucae Reg.) produces conidia which may germinate indirectly by production of zoospores or directly by germ tubes. It was discovered (1923) that conidia formed during cool weather produce zoospores most readily, especially in the dark at about 10° C., but during warm weather germination is largely direct.

Soil Moisture: Study of effects of varying soil moisture have been especially important with blackheart of celery, which causes a rapid and destructive yellowing, blackening, and collapse of the young leaves. Investigation showed (1924) that it was caused by improper water relations in the soil and would develop if the soil moisture suddenly approached the saturation point after periods of low moisture. High temperatures favor the disease.

Controlled experiments with blossom-end rot of tomatoes showed that plants grown continuously with a moderate supply of soil moisture were not subject to the disease but, when the water content of the soil was rapidly decreased after being very high, the disease regularly occurred. Excessive fertilization with nitrogen also increased the likelihood of incidence of blossom-end rot.

With club-root of cabbage a decrease in soil moisture was found (1930) to be accompanied by reduced infection, and in soils held constantly at a very low moisture level no infection occurred. However, a period of 18 hours at favorable moisture was found to be enough for infection. The progress of the club-root disease is checked in alkaline soils and it was shown that in well-watered soils with a pH of 7.2 or above there was little infection. In drier soils (1934) this did not hold, apparently because of a lack of sufficient movement of alkaline particles to neutralize the CO_2 constantly given off immediately about the rootlets where infection occurs.

Rainfall: Rainfall has been shown to be responsible for much of the dissemination of diseases such as angular leaf spot and anthracnose of cucumber (1920). Such dissemination has been of particular significance with black leg and black rot of cabbage (1922, 1934), where dissemination during the growing season is largely by rain. Both of these diseases are prevalent in the Eastern, Central, and Southern States but are almost unknown in Pacific Coast sections where most of the cabbage seed is grown. Study of the climatic conditions affecting disease development have shown (1934) that lack of rain during the summer discourages the development of black leg and black rot on seed crops in this section.

Light Intensity: With curly top of tomatoes and beans, (1924-1942) various studies of the effect of environment on the development of the disease showed that symptom expression is directly affected by light intensity, which, when reduced, will practically suppress symptoms of the disease. No definite effects of temperature, humidity, or rate of evaporation from the leaves could be found. Nutrition did not affect the incidence or development of the disease and biochemical studies did not show striking differences in diseased and healthy plants.

Nutrition: The effects of nutrition on the development of disease has been a subject of various field and laboratory investigations. With blackheart of celery, field experiments (1925) showed that the incidence and severity of the disease were not related to nutrition and that the amount or source of nitrogenous fertilizers used did not, as had been believed, influence the development of the disease.

Studies on the fungus causing cabbage yellows (1945) were conducted in sand cultures with susceptible, tolerant, and resistant plants. Disease was retarded by an increase in salt concentration except at very low levels. Low nitrogen and low phosphorus tended to retard and low potash to increase the progress of the disease, but suppression or increase in disease severity was not correlated with growth. The experiments were conducted at varying soil and air temperatures, and it was found that the effects of nutrients were conditioned by temperature and by the degree of host resistance.

It has been found (1941) that cabbage, cauliflower, turnip, and rutabaga are susceptible to injury by boron deficiency in the soil. In cabbage, the symptoms consist chiefly of the development of watersoaked spots in the fleshy pith of the core and stem, which may become brown; and hollow cavities develop at times. Cauliflower curds are discolored and the core is split. In turnips there is a discoloration of the roots, which develop a hollow center.

Phytotoxicity of Insecticide Residues: The question of possible phytotoxicity of residues of DDT and other new organic insecticides, with particular reference to the effects of their accumulation in the soil, is now under investigation. It has been shown that such effects may occur, and work is in progress with a number of vegetable and other crops.

Cultural Practices: It has been found that cultural practices may have a bearing on disease development. Tomato seedlings grown in the South for shipment to the North are pulled in the field and tied in bundles, which are usually left exposed to the sun for some time before removal to the packing house. Studies of stem infection by the fungus causing early blight (Alternaria solani (Ell. & Martin) Sor.) proved that susceptibility to stem infection increased with the degree of wilting of the plant. Slight mechanical injuries to the stem also increased the amount of infection (1942). Plants allowed to remain in the field too long before pulling showed significantly greater amounts of stem canker.

CONTROL OF VEGETABLE DISEASES BY METHODS OTHER THAN THE USE OF RESISTANT VARIETIES

USE OF FUNGICIDES FOR DISEASE CONTROL -- Early experiments in the use of fungicides for control of vegetable diseases (1904-08) were with bordeaux mixture for control of downy mildew (Pseudoperonospora cubensis (Berk. & Curt.) Rostow.) and anthracnose of cucumbers in the South. It was shown that spraying gave good increases in yield, and detailed directions were supplied for the preparation of the fungicide. In 1920 extensive experiments on the control of anthracnose of watermelon showed that the use of bordeaux mixture when, applied so as to give proper coverage of the vines, would greatly reduce losses from this disease.

Experiments on control of early blight (Cercospora apii Fres.) and Septoria spot (Septoria apii (Berk. & Curt.) Chester) of celery were conducted in Florida (1919-1924). A comparison was made between various formulations of bordeaux mixture and copper-lime dust in which bordeaux mixture gave definitely better control.

In experiments on control of Septoria leaf spot of tomatoes (S. lycopersici Speg.) (1919-1924), it was found that five applications were necessary to give effective reduction of losses from the disease and that at least 100 gallons of spray must be applied per acre. Trials were made with various strengths of bordeaux mixture and it was noted that a 4-2-50 formula gave good results, thus anticipating the later use of the low-lime mixture which is now commonly recommended. Additions of rosin-fish oil soap was thought to increase the effectiveness of the fungicide. It was pointed out that spraying was profitable only when the crop was grown on fertile soils and disease was severe.

In 1936 investigations were started on the control of diseases of tomato seedlings grown in the South for shipment to the North. The chief problem at that time was the control of Alternaria stem canker and leaf spot, but since 1946 there also has been the problem of late blight (Phytophthora infestans (Mont.) DBy.) control. Spraying and dusting experiments have continued to the present and have included tests in which the development of disease on plants treated in the seedling beds is observed after they have been transplanted in the North. Bordeaux mixture was found to be injurious to seedling plants and it was shown (1942) that when applied just prior to shipment many plants did not survive after transplanting in the field. Later work has shown that fixed copper fungicides can be used with safety and will give fairly adequate control of disease. Many of

the newer fungicides have been and are still being tested, particularly the carbamate compounds which show definite promise for use on seedlings.

In experiments on the control of tomato anthracnose (Colletotrichum phomoides (Sacc.) Chester) spraying with ziram and ferbam gave control superior to copper fungicides and appeared equally effective against early blight (1947).

Experiments with fungicides for control of rust of beans showed (1946) that sulfur is extremely effective in rust control. Investigations on field beans in the West have proved that two applications per season may increase the yield of seed as much as 1,000 pounds per acre, and a single application gave increases as high as 600 pounds per acre. Work on powdery mildew of beans (Erysiphe polygoni DC.) in the South (1936) also demonstrated the value of sulfur dust in the control of this disease. Studies on the control of Sclerotinia infection of beans in Oregon indicate (1950) that aerial infection can be much reduced by spraying with ziram plus a wettable sulfur. Promising results also were obtained with ziram and sulfur used singly, bismuth subsalicylate, ferbam plus sulfur, copper-zinc, and copper-zinc chromate. Dusting with ziram and wettable sulfur also reduced aerial infection. No control of basal infections was obtained by use of fungicides. The degree of control obtained to date is still short of what is required for most satisfactory commercial production.

SEED TREATMENT -- Several types of seed treatment for control of vegetable diseases have proved of definite value. In 1920 it was shown that losses from angular leaf spot of cucumber and anthracnose of cucumber and melons could be reduced by treatment of the seed with a 1-1000 solution of bichloride of mercury. Field tests showed the effectiveness of the treatment, which was soon widely used on seed of pickling cucumbers and continues to be used today.

Treatments of cabbage seed as an aid in control of black leg and black rot were tested (1924), and it was found that, while a 1-1000 solution of bichloride of mercury would effectively kill the black rot bacteria it would greatly reduce but not entirely destroy the black leg fungus. This was recognized as a serious limitation in the treatment and it was shown that a hot water treatment for 30 minutes at 122° F. would free the seed of both organisms, although there was danger of injury to germination. This latter method has since become the one recommended, because of increasing evidence of the limitations of bichloride of mercury for black leg control.

Investigations of seed transmission of tomato bacterial canker showed that treatments with bichloride of mercury and other chemicals did not effectively free the seed of the canker bacteria, particularly when used on freshly extracted seed. However, it was found (1933) that fermentation of freshly extracted seed and crushed fruit pulp for 96 hours at temperatures close to 70° F. gave very effective control of seed-borne infection. Later it was found that seed extracted mechanically without fermentation could be effectively disinfected by soaking for 24 hours in an 0.8% solution of acetic acid. Both treatments proved definitely superior to previous chemical treatments.

SANITATION -- Sanitation as a factor in disease control has presented important possibilities in the case of certian virus diseases. Many investigations also have shown the danger of contamination of seed bed and field soils with certain parasitic fungi and bacteria and recommendations have been made for methods of avoiding such contamination.

With cucumber mosaic the discovery of the overwintering of the virus in perennial weed hosts led to extensive field experiments on the control of the disease by eradication of wild hosts (1926). Experiments with an isolated field with a known history of severe mosaic damage on successive cucumber crops resulted in the occurrence of only slight losses when milkweed was destroyed in its immediate vicinity. Further work with a group of commercial plantings where the disease had been severe demonstrated the practical possibility of control by the grower. It was found that such perennial weeds as milkweed and Physalis spp. need to be kept down only in the immediate vicinity of the fields to secure adequate control.

In Florida it was found that the southern celery mosaic virus occurred on the creeping day flower (Commelina nudiflora) along ditch banks, roadsides, and frequently near seedbeds, and a study of the progress of mosaic in the field showed that the first infection commonly occurred adjacent to the spots where this weed was growing. Experiments in which the weeds about certain fields were destroyed by cultivation or chemical treatment demonstrated that the incidence of mosaic could be greatly reduced by such methods.

In work on the control of cabbage mosaic in seed-crop cabbage fields in the Pacific Northwest (1946), it was shown that losses from mosaic, which had previously been severe, could be greatly reduced by locating the seedbeds on farms outside the district in which the seed crop is grown. The adoption of this method has resulted in a sharp decline in the occurrence of mosaic on the seed crop.

OTHER METHODS OF CONTROL -- Other methods being tested for disease control include the application of cyanamid to the soil in advance of planting as a means of reducing the severity of Sclerotinia on beans in Florida. On marl soils this method shows promise but on sandy soils it has not been effective. In the same investigations (1949) it was found that, where feasible, the flooding of the fields for four or five weeks during the summer was a means of killing the sclerotia, which soften and rot under such conditions.

The fact that shade reduces the incidence and expression of curly top in tomato and beans has been used in a method of control that, while not adapted to commercial use, has value for the home gardener. The effect of shade is due largely to the fact that the leafhopper vector does not frequent shaded locations, but there also is an arresting effect on the development of the disease in infected plants. Shading with slatted or muslin-covered frames has been found to reduce the losses considerably, and some protection also has been found (1938) when small plants are protected by tent-like strips of muslin when small. After the plants touch the cloth it is removed and at this stage of growth the likelihood of injury is much reduced. In commercial field plantings of tomatoes it also has been found (1942) that close planting (10 inches) within rows of normal width considerably reduces losses from the disease and increases yields.

DEVELOPMENT OF VARIETIES RESISTANT TO DISEASE

BEANS -- Research on the development of beans resistant to disease was initiated in 1921. Between then and 1925 a large collection of varieties and hybrids was assembled and tested for resistance to various diseases. Gradually the work became concentrated largely on development of resistance to rust, virus diseases, and halo blight. In 1940 varieties of Kentucky Wonder, No. 3 and No. 4, which were resistant to a number of races of rust, were introduced. Studies of inheritance to six races of rust showed (1941) that resistance to races 1 and 2 was due to a single dominant factor, but more than one factor was involved with the others. Resistance was dominant in the case of four races and incompletely so in two. In 1946 two varieties of field beans with high resistance to many races of rust, Pinto No. 5 and Pinto No. 14, were introduced. These are proving valuable in the West, where rust is a serious problem in field beans.

Resistance to mosaic in beans was studied in the trials of 1921-25, but only the variety Robust showed resistance. In later work (1935) the variety U. S. No. 5 Refugee, which is resistant to common mosaic, was introduced. In 1942, Logan, a variety resistant to powdery mildew and to common mosaic, was released. This variety is especially suited to the South. In 1948 a mosaic-tolerant bean, Rival, and also Contender, a variety resistant to powdery mildew and mosaic, were introduced and in 1949 a mosaic-resistant variety, Topcrop, was released. Work on resistance to halo blight and on multiple virus resistance is in progress, and efforts are being made to develop lima bean varieties resistant to downy mildew (Phytophthora phaseoli Thaxt.) and to nematodes.

Curly top is very destructive to beans in many parts of the West, particularly in Eastern Oregon and Washington. Work on the development of snap beans resistant to the disease has been in progress for some years, but the only resistant parental material so far discovered has been limited to field bean varieties such as Red Mexican, California Pink, and Burtner, the last-named a variety whose young pods can be used as snap beans. The work of combining adequate horticultural type with resistance has been difficult in hybrids of these varieties with snap beans. In 1943, Pioneer, the first curly-top-resistant snap, was introduced. It is not suited to commercial use but provides home gardeners with a snap bean that can be grown successfully where all susceptible varieties fail because of curly top injury. Recent work gives promise of ultimate production of resistant snap beans of desirable quality for general commercial use. In this work mosaic resistance is being combined with resistance to curly top.

CABBAGE -- The work on development of cabbage varieties resistant to disease began with research on cabbage yellows in 1918. The fungus causing yellows (Fusarium oxysporum f. congutinans) was a serious menace to the crop in many sections of the Central, Eastern, and Southern States and although two yellows-resistant varieties had been produced by the Wisconsin Agricultural Experiment Station, it was evident that a number of resistant kinds were needed to suit varying climatic conditions and seasonal and market requirements.

It was known that the earlier resistant varieties varied in their behavior with respect to disease. Later it was found that their susceptibility increased with high soil temperatures. Investigations on the effect of temperature on the disease had shown that plants homozygous for resistance remained healthy at constant temperatures of 26° C., while the older varieties either showed no resistance or only a certain percentage of the plants survived. It was thus evident that a more

complicated resistance, known as Type B, existed in such varieties, in contrast to the Type A resistance of the homozygous-resistant lines. This latter type, which is governed by a single gene dominant over susceptibility, was the first such single-factor difference to be reported for diseases caused by vascular Fusaria.

In the later breeding work the difference in reaction to soil temperature proved to be a very useful means of selecting individuals carrying the A type resistance in breeding progenies. This type was found to be present in most of the older varieties of cabbage used in this country, although only a small percentage of the plants carry it. Continued work on resistance has resulted in the introduction of a series of resistant varieties ranging from early to late season types and carrying close to 100 percent Type A resistance. At present the list includes varieties which supply resistant counterparts of all of the commercial varieties in common use and in many cases these are superior to the older types in horticultural quality.

Histological studies (1930) have shown no morphological difference in the roots of resistant and susceptible cabbage plants that would account for resistance. Later work (1935) on penetration by the fungus of the roots of resistant and susceptible plants showed that with Type A resistant seedlings the fungus may invade the cortex slightly but does not become established in the vascular system. In plants with Type B resistance there is some vascular invasion but it is restricted to a few localized vessels. In susceptible plants the fungus readily traverses the cortex and enters the vascular system. Resistance appears to involve degree of invasion and no morphological differences are apparent.

Work on resistance to club root of cabbage has been in progress for some time and has proven a more difficult problem than that of yellows resistance. Trials have shown no varieties of cabbage, cauliflower, brussel sprouts, kohlrabi, or collards possessing any resistance to the disease. Garden kale also is susceptible but certain stock kales have high resistance. Tests of club root resistance in turnips (1939) showed that some varieties are resistant and other susceptible. These results are in accord with those of workers in Europe. Most varieties of rutabagas tested showed no infection on infested soils. This fact indicates that there may be a difference in the pathologic behavior of certain strains of the club root organism, since in Europe some of the varieties tested have been found very susceptible. A study of the pathogenicity of the organism as collected from widely distant localities in this country indicated little difference in pathogenicity.

Attempts at securing crosses of cabbage with resistant varieties of turnips have failed, and similar crosses between resistant kales and cabbage have proven difficult. However, a cabbage-kale cross was found in the field and has been used in breeding work that is now in progress. Studies on the nature of resistance (1939-1945) to club-root has thrown much doubt on the European theory that resistance in black mustard is related to the presence of allyl isothiocyanate. Some collections of mustard have proved very susceptible and work with its volatile oil and with a related compound have shown no correlation between oil content and resistance in the plants tested.

CUCUMBER -- Work relating to disease resistance in cucumber has been confined to mosaic and bacterial wilt. Extensive tests of native and foreign varieties (1933-35) showed that in the varieties tested, aside from Chinese Long whose mosaic resistance was already recognized, only two varieties, Tokyo Long Green and Tokyo Dark Green, possessed marked resistance to mosaic. These varieties appeared to be practically identical in horticultural characters. Strains of Chinese Long and Tokyo Long Green were developed that possessed high mosaic resistance, and in field tests it was found that the latter variety showed definite tolerance of bacterial wilt infection. Hybrids of Tokyo Long Green and a variety known as Vickery's Forcing showed increased resistance compared to that of Tokyo Long Green, and certain hybrid selections were obtained that showed marked tolerance (1938) but whose horticultural characteristics were not fully desirable. In 1942 this work was held in abeyance because of need for work on more important food crops during the war and has not yet been resumed. Seed stocks are being maintained and testing for disease resistance has been continued with foreign cucurbit introductions.

MUSKMELON AND WATERMELON -- The development of disease resistance in muskmelons has been chiefly concerned with resistance to powdery mildew, which about 1925 began to cause extreme losses on melons in the Imperial Valley of California. Control of the mildew could be secured by application of sulfur but most varieties were so badly injured by it that sulfur could not be used effectively. Varieties resistant to mildew or to sulfur offered the only solution of the problem. A large number of native and foreign varieties were tested for resistance to mildew. In 1928 evidence of high resistance was found in certain virtually inedible varieties from India.

These were crossed with commercial varieties and in 1932 the first mildew-resistant variety, No. 50, was introduced. It was derived from a cross with Hale Best and represented a most valuable accomplishment in breeding. Further breeding work resulted in the development of an improved variety, Hales No. 45, which was of excellent quality and protected the industry from losses from mildew until 1938, when a new strain of the mildew fungus, Race 2, appeared. Since varieties resistant to Race 1 were susceptible to Race 2, further breeding work had to be undertaken. It proved possible to develop varieties resistant to Race 2, and between 1943 and 1946 two resistant varieties were introduced. One of these, Powdery Mildew Resistant Cantaloup No. 5, has since been very generally used, although Powdery Mildew Cantaloup No. 6 is also grown.

In the course of the work on mildew resistance various pathological investigations have been made in relation to resistance. The reaction of 21 species in the Cucurbitaceae to artificial infection with powdery mildew has been determined (1945), and there have been studies of correlated resistance in leaves, cotyledons, and stems of muskmelon. In 1942 it was shown that the addition of Vitamin B_1 to the soil in some way increased the growth of the powdery mildew fungus on cantaloups, although it could not be determined whether this was because of a direct effect on the parasite. When excised inoculated leaves were maintained on a sucrose solution to which Vitamin B_1 had been added, no significant effect on mildew development occurred. At the present time work is in progress on development of mildew-resistant Honey Dew and Honey Ball types of melons and further development of high-quality resistant cantaloups.

The increasing severity in losses from mosaic on cantaloups in the Imperial Valley has led to a search for simply inherited and potent resistance to the complex of three mosaic viruses that affect the crop. A number of mosaic-tolerant and mildew-resistant forms of inedible melons have been found and are being tested in hybridizing with commercial varieties.

Work on disease resistance in watermelons has resulted in the development of a variety Congo (1949), which possesses a certain degree of resistance to anthracnose, is a good shipper, and is of exceptional quality.

LETTUCE -- Breeding for disease resistance in lettuce has largely been concentrated on brown blight and downy mildew. Brown blight, a soil-borne disease of unknown cause, appeared in southern California and Arizona about 1918 and by 1923 had caused serious alarm. In 1923, 100 varieties of lettuce were grown on infested soil and only two, Big Boston and Chevigne, remained disease-free. Second-generation plants of a Chevigne x New York cross showed an approximate 3:1 segregation for resistance. Later, resistant plants were found in a badly diseased field of variety New York and selections were made from these plants. Eventually the resistant progeny of one such plant was released (1926) as the variety, Imperial No. 2.

Lettuce downy mildew also was cuasing losses in the same area. It was demonstrated (1924) that four races of the fungus existed. A variety of European origin was found to be highly resistant to the disease. By crossing this variety with several strains of New York it was possible to produce desirable varieties of the New York type resistant to the four known races of mildew. These also were released under the name Imperial followed either by a letter or a number, a system which has been continued with later introductions. In 1932 another physiologic race (Race 5) of the downy mildew fungus appeared, and all of the strains of lettuce resistant to the other races were attacked by it. In a series of extensive tests, two primitive and commercially useless European varieties proved immune and were used in the development of new strains of resistant lettuce. It was found (1940) that resistance to Race 5 and one of the other 4 races was controlled by a single dominant gene. Indirect evidence was thought to suggest the origin of new races of the fungus through mutation. Later investigations have dealt chiefly with the development of varieties of improved quality and increased resistance.

ONION -- The earlier work on disease resistance in onions dealt to a considerable extent with the nature of resistance to onion smudge (Colletotrichum circinans (Berk.) Vogl.), which is not highly destructive but causes slow shrinkage and injures the appearance of onions in storage. Studies (1920) demonstrated that, in yellow and red varieties which are resistant to the attack of the fungus, the watery extracts from the dry outer scales of colored varieties prevented germination and caused the rupture of the germ tubes of spores of the fungus. Extracts from white outer scales supported a normal growth of the organism. When the outer scales were removed spore germination occurred normally on the fleshy inner scales in both white and colored varieties and there was no exclusion of the fungus. Resistance was, therefore, expressed only in the outer dry scales and was associated with the coloring materials in the yellow and red varieties. Chemical studies of the toxic extracts from the scales resulted in the identification and isolation (1929-1935) of two phenolic compounds, protocatechuic acid and catechol, which are water-soluable and

responsible for the resistance in colored outer scales. This work represented the first identification and isolation of a definite chemical substance responsible for resistance to a plant disease.

In recent years the onion investigations have included studies of resistance to pink root (Phoma terrestris Hansen), smut (Urocystis cepulae Frost), and smudge. Studies have been made of smut resistance in hybrids of Allium spp. (1944), factors affecting pathogenicity in pink root (1948), and the reaction of onion varieties to isolates of the pink root fungus (1948).

SWEETPOTATOES -- Research on disease resistance in sweetpotatoes has dealt chiefly with resistance to Fusarium wilt. Trials made as early as 1914 showed that certain varieties possessed varying degrees of susceptibility to wilt. Later tests (1927), conducted with 21 varieties over a period of four years, demonstrated that while all the popular table type varieties were very susceptible, certain other varieties showed considerable resistance.

After 1938 work was started on the development of varieties of superior horticultural type which also possessed resistance to wilt. In the course of work on production of varieties with high starch content for commercial use, evidence of wilt resistance was found in certain lines and these were used as parental material in the breeding of table stock. One variety, Allgold, which shows a certain degree of resistance to wilt has been introduced. Numerous seedling selections possessing more or less resistance to wilt, but not yet released as varieties, are being tested for eating quality and cultural characteristics. In more recent work, highly resistant parental stocks have been found in material from foreign countries. Certain Japanese varieties possess high wilt resistance and a very recent introduction from Tinian Island in the Pacific is very highly resistant and transmits the resistant character well to hybrid progenies. Work is now in progress on the development of varieties through hybridization with these stocks. The work has been facilitated by the development of methods for greenhouse testing for resistance.

TOMATO -- Work on disease resistance in tomatoes began in 1915 and for some years was concentrated on the development of varieties resistant to Fusarium wilt, which was causing increasing losses in the South. Between 1917 and 1922 a number of varieties were introduced that possessed considerable wilt resistance. In one of these, Marvel, wilt-resistance was exceptionally high and uniform. Between 1918 and 1928 nailhead spot had become increasingly serious as a disease of tomato fruits and threatened to destroy the tomato shipping industry in Florida. Marvel, which had shown striking resistance to fruit infection by the nailhead spot fungus, was crossed with Globe, which had the horticultural qualities desired by southern growers but was very susceptible to the disease. As a result, the variety Marglobe, which possessed high resistance to nailhead spot and also was highly tolerant of wilt, was introduced (1925). Its introduction saved the shipping industry in the South, and until the appearance of Rutgers (1934) it was the most important tomato variety. Later, Break O'Day, Pritchard, and Glovel, the last a "sister" of Marglobe but with pink fruit, were introduced. These varieties were all resistant to Fusarium wilt and to nailhead spot.

In further work on resistance to wilt a method was devised (1941) whereby large numbers of seedling plants were rapidly tested for resistance in the greenhouse. This method, which included the use of high virulent isolations of the wilt Fusarium, made it possible to subject plants to a much more severe test for resistance than had been possible in the field. Using this method it was found that a strain of the red currant tomato (Lycoperiscon pimpinellifolium (Jusl.) Mill.) from Peru was practically immune to wilt infection. Inter-specific crosses were obtained with Marglobe and by backcrossing and selection a variety, Pan America, was produced (1941), in which resistance to wilt was so high as to approach immunity. While Pan America has not had wide commercial use, it has been of great value in incorporating wilt-resistance in other varieties developed for resistance to various tomato diseases. In 1949 a yellow tomato of high wilt-resistance, Sunray, also was introduced.

In the course of pathological investigations on resistance to Fusarium wilt, it was shown (1945) that when Pan America scions were grafted on stocks of the susceptible variety Bonney Best a considerable percentage of the Pan America tops developed symptoms of wilt. When Bonny Best scions were grafted on stocks of Pan America, 90 percent of the tops remained healthy. It appeared that the factor for resistance to Fusarium wilt was confined to the root and was not transportable to the tops.

In other work (1945), in cooperation with the Bureau of Agricultural and Industrial Chemistry, a substance extracted from tomato plants was found to inhibit the growth of spores of the wilt fungus in culture. This material, known as tomatin, was present in nearly equal amounts in both resistant and healthy varieties, although slightly more was present in plants of the highly resistant species of Lycopersicon pimpinellifolium. It was found that the tomatin content was highest

in leaves, with less in the roots, and very little in stems or fruits. Plants affected with *Fusarium* wilt showed a decreasing tomatin content as the disease progressed, while plants wilting and dying from mere lack of water showed no comparable decrease. The material in the plant extract has been found to be a glycosidal alkaloid. The relation of this substance to resistance to wilt has not yet been definitely determined.

In 1937-1938 the Division of Foreign Plant Exploration and Introduction collected a large number of strains of nearly all wild species of *Lycopersicon* in South America. This material has been extensively tested and has proved of great value, since several of the species have been found to be resistant to various tomato diseases. It has been found that *L. hirsutum* H. & B. is resistant to *Fusarium* wilt and also to leaf infection by *Alternaria solani*. Another species, *L. peruvianum* (L.) Mill., also has *Alternaria* leaf spot resistance. Crosses between *L. hirsutum* and cultivated tomatoes are readily obtained, but hybridization with *L. peruvianum* has presented great difficulty. However, such an inter-specific cross was secured (1945) and has since been used in studies on resistance to *Alternaria* leaf spot. Strains of *L. pimpinellifolium* also have been found showing resistance to this disease. Work is now in progress on the development of varieties possessing resistance to wilt, *Alternaria* leaf spot and stem canker, and to leaf infection by *Stemphylium solani* Weber. Resistance to *Alternaria* stem canker has been secured in several lines and some degree of resistance to leaf infections. Testing for resistance to stem canker and foliage infections has been facilitated by a method of dipping seedling tops and stems in a suspension of macerated fungus mycelium and then holding the plants in a moist atmosphere for 48 hours. A variety, Southland, introducted in 1948 possesses high resistance to *Alternaria* stem canker and *Fusarium* wilt. It also possesses a moderate degree of resistance to *Alternaria* leaf spot and to one form of late blight, although it is not resistant to other forms of the latter disease.

Two varieties of tomato, Riverside (1937) and Essar (1939), have been produced which possess some resistance to both *Verticillium* wilt (*Verticillium albo-atrum* Reinke & Berthold) and to *Fusarium* wilt. These varieties were developed for use under California conditions. In later work it was found that a strain of the red currant tomato and also one of the "cherry" type showed high resistance to *Verticillium* infection. Hybrids with the cultivated tomato gave progenies showing resistance, and continued selection and outcrossing gave resistant plants with fruits of marketable size. However, resistance has been coupled with low yields and late ripening and the work is still in progress. Recent development of a method for testing large numbers of seedlings in the greenhouse is speeding the work of selection and breeding, and certain selections now appear to have fair fruit size and earliness.

In breeding for resistance to curly top the early work yielded no evidence of resistance in a very extensive collection of foreign and native varieties of the cultivated tomato. A semi-wild, small-fruited Mexican type showed some resistance but in several years of crossing and selection it was found that this resistance could not be increased to where it was likely to be of great value. Tests with wild species from South America demonstrated that strains of *Lycopersicon peruvianum* var. *dentatum* Dun. and *L. glandulosum* C. H. Mul. were highly resistant though not immune to curly top. Crosses could not be obtained directly with these species and *L. esculentum*, but the cross *L. esculentum* x *L. hirsutum* was made and the progeny was crossed with *L. peruvianum* v. *dentatum*. The resulting progeny had very small fruit, and as fruit size increased resistance tended to decrease. For some years the work of selection was limited by the necessity of testing for resistance in the field at locations where consistent severe curly top infection was assured. Recently (1949), a method of greenhouse testing has been devised by which thousands of seedlings can be eliminated as effectively as under field conditions. This has greatly speeded the work of selection for resistance in a large population of selected progenies. The work is being continued and at present certain selections of most promise are being tested in the field in various localities where the disease occurs.

Investigations showed (1949) that some plants of *Lycopersicon hirsutum* possessed considerable tolerance of tobacco mosaic. Continued investigation resulted in the finding of two plants with extremely high resistance to mosaic. Hybrids of these plants and cultivated tomato varieties have given progenies some of which show high tolerance to artificial inoculation with the yellow and green strains of tobacco mosaic virus. It also has been found (1948) that they are less readily infected by natural means than commercial tomato varieties. Resistance has tended to be coupled with small fruit size but selections of resistant plants with fair-sized fruits recently have been secured.

CONCLUSION

This record of vegetable disease research in the Department of Agriculture is but a typical segment of the work of plant pathologist throughout the United States during the past fifty years. We have gained a substantial knowledge of fungus, bacterial, and virus diseases of vegetables and in many instances have developed means for their control. The advent of organic fungicides and insecticides holds further promise of reducing losses from certain diseases, hitherto difficult to control. Likewise, the period since 1925 has been marked by an intensive study of disease resistance. The striking success that has attended such work has served to stimulate the extensive program of work on disease resistance that is now in progress throughout the country.

DIVISION OF FRUIT AND VEGETABLE CROPS AND DISEASES, BUREAU OF PLANT INDUSTRY SOILS, AND AGRICULTURAL ENGINEERING

INVESTIGATIONS ON POTATO DISEASES BY THE BUREAU OF PLANT INDUSTRY, SOILS, AND AGRICULTURAL ENGINEERING, UNITED STATES DEPARTMENT OF AGRICULTURE, 1910 to 1949

E. S. Schultz

The Irish potato is a favorable host for many fungus pathogens, including species from the slime molds to the smuts and rusts. It is also a favorable host for certain mosaic viruses, as represented by viruses A, X, and Y, and the yellows viruses causing leaf roll and witches'-broom. Certain nematodes also seriously affect potatoes. Most of the fungus pathogens invade the tops, as well as the tubers; others attack only the tops or only the tubers.

Though many diseases can infect the potato, rarely more than several diseases in a single season constitute limiting factors in potato production in any one locality. However, one disease like late blight can cause potato failure unless control measures are practiced.

In the Bureau of Plant Industry, Soils, and Agricultural Engineering, United States Department of Agriculture, investigations on potato diseases were initiated about 1910 by W. A. Orton, in charge of the Office of Cotton and Truck and Forage Crop Disease Investigations. These investigations have been continued by various staff members. During this period primary attention has been given to such diseases as wart, powdery scab, late blight, Fusarium wilt, Fusarium and bacterial rots, blackleg, bacterial ring rot, common scab, and virus diseases.

LATE BLIGHT: Late blight, one of the serious potato diseases where favorable moisture and temperature prevail, was one of the first diseases to receive major attention. In 1861 de Bary first recorded experimental evidence that the late blight fungus, Phytophthora infestans, is able to spread from infected seed tubers into the shoots and subsequently infect the foliage by spores from the infected shoots. Most investigators, following de Bary's work, failed to confirm his results. Other theories as to the yearly occurrence of late blight were that the mycelium overwinters in the soil; that resting spores are produced; that the mycelium is latent in the plant; that the fungus sporulates on the seed tuber in the soil, and the spores reach the surface of the soil and cause foliage infection; and that sclerotia-like bodies or a mycoplasm gives rise to infection. Inasmuch as considerable negative evidence on all but the perennial-mycelium theory had been presented, investigations were initiated on the perennial-mycelium hypothesis.

Investigations on the life history of the late-blight fungus conducted in the greenhouse and field disclosed that tubers infected with late blight from which sprouts become invaded by the fungus hyphae are the primary source for infection of potato tops in commercial potato fields.

Observations on primary infection of potatoes in potato fields in Aroostook County, Maine, showed that potato cull or waste piles, harboring late blight tubers, are primary sources for initiating late blight infection in commercial potato fields. Fields near potato waste piles are the first to become infected with blight and frequently become infected when the plants emerge and before spraying with fungicides commences. Potatoes harvested from fields infected with late blight before the foliage is killed by frost or by other means have confirmed earlier observations that over 50 percent of the tubers may become infected with late blight at harvest.

Observations on the reaction of different European and American potato varieties to late blight indicated that some varieties were more blight-resistant than others. Later work has shown that apparently blight-immune varieties can be developed and that the late blight fungus involves several races so that a variety immune from certain races is not necessarily immune from all races.

POWDERY SCAB: Investigations on the life history, occurrence, and control of powdery scab were begun in 1914 when, on account of this disease, a Federal quarantine was declared against Canada and Maine. The investigations on powdery scab disclosed that this disease was favored by heavy, wet soil in the cool, northern potato regions and that it was rarely developed to a serious degree in the South.

Studies on the life history of Spongospora subterranea, the cause of powdery scab, disclosed that a uninucleate spore in germinating produces an amoeba, that the potato tissue is first invaded by the fungus in the plasmodium stage, that the plasmodium invades the tissue between the cells, as well as penetrates the cells, and that the cell walls in contact with the plasmodium are somewhat swollen and show special affinity for the orange-G stain.

Several saprophytic and parasitic fungi were found to be associated with dry rot that secondarily involved many powdery scab lesions. Among them a species of Phoma, a wound parasite, occurred frequently. Growths resembling nematode galls or legume nodules were found on potato roots, generally appearing before tuber infection occurred. Roots of tomato and several other solanaceous plants were found to be susceptible to powdery scab.

Though none of the control measures used absolutely inhibited powdery scab, seed-potato treatments with mercuric chloride and formaldehyde reduced seed-borne infection, and sulfur at the rate of 900 pounds per acre reduced infection from the soil.

POTATO WART: The discovery of potato wart in the United States in 1918 by J. G. Sanders created an interest in studies on wart, which was regarded as a menacing disease. Though comprehensive investigations on the life cycle of the potato wart fungus, Synchytrium endobioticum, had been made by Percival and Curtis in England, it appeared desirable to investigate the pathological anatomy and the environmental conditions, such as moisture, temperature, soil reaction, etc., under which potato wart develops.

Anatomical studies disclosed that the wart can be considered a foliar branch system. It is a homoplastic growth with quantitative reduction in vascular tissue and increase in storage parenchyma. There is a complete but gradual transition from normal to wart tissue. Although wart shows both qualitative and quantitative reduction of tissues, there exists, nevertheless, a marked similarity between structure of normal host and wart.

Investigations on the influence of environmental conditions on the wart fungus and infection showed that a vigorous growth of the potato plant favored infection; water is essential for germination of soral and resting sporangia, as well as for dissemination of the motile cells; intermittent flooding and aeration are most favorable for germination; infection from soral sporangia occurs between near 0° and 30° C.; with variable soil temperature infection occurs when the mean is about 21° C.; and the soil reaction most favorable for infection ranges from about pH 3.9 to pH 8.5. Only certain solanaceous plants were susceptible.

Studies on the reaction of different American potato varieties to wart were made to ascertain whether differences in varietal resistance appeared such as were found among British potato varieties. Irish Cobbler, Spaulding Rose, McCormick, Burbank, and Green Mountain were found to be immune, whereas Triumph, Early Rose, Early Ohio, Rural, Pearl, American Giant, and Up-to-Date are susceptible. As immunity from wart appears to be constant in certain potato varieties and is heritable in a definite manner, the use of wart-immune varieties ensures effective control of this disease.

TUBER ROTS: Reports from potato growers, dealers, transportation companies, consumers, and the Food Products Inspection Service of the Bureau of Markets, United States Department of Agriculture, indicated that considerable loss resulted from potato tuber decay. As a result, cooperative studies were begun by the Inspection Service of the Bureau of Markets and by pathologists of the Bureau of Plant Industry. Under this program investigations on the causes and control of potato-tuber rots and losses appearing in storage, transportation, and marketing were conducted.

The results of these investigations disclosed that: Fusarium tuber rot was one of the primary causes of losses in storage; handling injuries resulting in cuts, bruises, and skin abrasions are primary sites of Fusarium rot; frost injury and late-blight rot are also followed by Fusarium rot; sunscald and freezing injury followed by slimy soft rot are responsible for major potato tuber losses in transportation and marketing; late blight tuber rot causes considerable loss in storage and on the markets; refrigeration during transportation and storage greatly reduces tuber rots; and careful handling in harvesting, storing, transporting, and marketing to prevent mechanical injury is essential to control storage rots.

Investigations on wound cork formation in potato tubers confirmed earlier findings that moisture and temperature are closely associated with suberization and periderm formation, and that the origin of decay at the central portion of the exposed surface of cut tubers is correlated with the slower healing of this tissue when compared with that of the periphery. Seed-piece decay increases in direct proportion to the degree of drying; water loss retards cork formation and favors fungus invasion.

In addition to causing tuber rot some Fusarium species also cause wilt. Although some workers claimed that infected seed tubers were an important source of infection, observations in certain irrigated areas indicate that soil infestation is the primary source of seed-piece and root infection with Fusarium oxysporum. Suggested methods for control of Fusarium wilt include long rotations, planting whole seed potatoes, and use of resistant varieties.

Studies on vascular discoloration of potato tubers disclosed that discolored bundles were often sterile, whereas apparently normal tissues frequently yielded parasitic fungi. Of 3,043 platings made from discolored tissues, only 58 percent gave fungus growth; and the organisms found, in descending order of frequency, were Fusarium, Alternaria, bacteria, Verticillium, Penicillium, Colletotrichum, Rhizoctonia, and miscellaneous organisms.

Investigations on the etiology of potato-stem lesions have shown that certain strains of

Rhizoctonia, several parasitic species of Fusarium, as well as Alternaria, Botrytis, Sclerotinia, Zygorhyrnchus, Corethropsis, Phoma, Clonastachys, and Acrostalagmus can cause lesions on potato stems.

COMMON SCAB: The common scab fungus, Streptomyces scabies, is harbored by certain soils throughout the potato areas of the world. Infected tubers also harbor the scab fungus in the corky lesions and thus serve as a source of infection for the new crop. The scabby lesions mar the appearance of the tubers, contribute to waste in peeling, and disqualify infected tubers for first-class grades of table or seed potatoes.

Studies on the scab fungus have shown that a number of strains of this organism exist in the soil. Cultural studies revealed that some isolates mutate more than others and differ in type and color of mycelium and in color of pigment produced in the medium. Color of mycelium or medium appears to be related to degree of parasitism. Mutation of the fungus did not appear to be affected by hydrogen-ion concentration, temperature, or nutrients. Although the reaction of a variety may vary with the strain of the scab fungus, studies on scab resistance in potatoes indicate that this resistance is relatively stable.

Inasmuch as seed-potato and soil treatments have not been generally satisfactory for control of common scab, and experience has shown that varieties vary in their reaction to the common scab fungus, investigations on breeding potatoes for resistance to common scab were initiated in 1930 under the National Potato-Breeding Program. These breeding studies have disclosed that many varieties manifest marked scab resistance. As a result of this work and that of State agricultural experiment stations the scab-resistant varieties Menominee, Ontario, Cayuga, Seneca, and Yampa have been developed as commercial varieties.

SEED-POTATO TREATMENTS: Seed-potato treatments for the control of such tuber-surface borne diseases as common scab and Rhizoctonia canker have been used and generally recommended. The earlier work indicated that formaldehyde controlled blackleg, whereas corrosive sublimate was more effective against Rhizoctonia. Though these treatments appeared effective in some areas, they did not give generally satisfactory results. In view of this experience, and with the availability of newer products like the organic mercuries that were developed during the first World War, the desirability of further studies on seed-potato treatments was indicated.

Seed-potato treatments with clean and Rhizoctonia-infected Irish Cobbler were conducted in northern Maine from 1925 to 1933 to ascertain the effect of different disinfectants on disease control, yield, and soil infestation.

The results of these tests showed that corrosive sublimate was one of the most effective treatments for Rhizoctonia control; certain organic mercury compounds also gave good control; treating seed potatoes heavily infected with Rhizoctonia significantly increased the yield; in two of the nine seasons when seed-piece decay appeared, certain treatments effectively controlled seed-piece decay; treating clean seed did not affect the yield; and certain soils are free from Rhizoctonia infestation. Selecting Rhizoctonia-free seed potatoes and planting them on clean soil results in Rhizoctonia-free potatoes even in the absence of seed-potato treatment.

VIRUS DISEASES: Potato diseases described as a "curled disorder of potatoes" were recognized early in the nineteenth century, but apparently did not begin to attract serious attention until early in the twentieth century, when leaf roll appeared in epiphytotic outbreaks in important potato areas of Europe. During this period hypotheses as to the cause of leaf roll and similar diseases were as numerous as the workers. Some of the early workers held that leaf roll was caused by fungi, but after about 1914 most of the workers on leaf roll and similar diseases began to regard them as non-parasitic and heritable; i.e., transmitted from one generation to the next through the tubers.

Mosaic on potato was observed by W. A. Orton in 1911 in a field at Giessen, Germany. In extended surveys throughout the leading potato areas in the United States during the growing seasons of 1912 and 1913 he found leaf roll, curly dwarf, and mosaic on certain potato varieties. In his 1912 survey in Maine, Orton observed fields of Green Mountain that had practically 100 percent mosaic, whereas other fields had less than 10 percent of the plants affected by mosaic.

Though the causal agent, the means of spread, and the types of mosaic, leaf roll, curly dwarf, and mosaic were obscure, Orton in 1914 recorded a diagnostic description of these potato disorders that he termed leaf roll, curly dwarf, and mosaic. As an effective control for these diseases he recommended the use of disease-free seed potatoes to be selected as a result of field inspection under a program of seed-potato certification by the seed-potato-producing States.

Intensive investigations on the nature, means of dissemination, and control of virus diseases of potatoes were initiated by the Bureau of Plant Industry, Soils, and Agricultural Engineering

during the second decade of the twentieth century. At this time, none of the potato virus diseases had been experimentally transmitted from diseased to healthy plants, although observations indicated that leaf roll was harbored by tubers from plants infected with leaf roll. Mosaic was regarded as being caused by a single virus and associated with progressive deterioration of the affected plants from season to season.

Before the potato virus diseases were transmitted artificially, some workers held that the causal agent invaded the seed piece from the soil, whereas laymen held that the weather was the causal agent. Senescence, physiological deterioration, and other ideas involving the concept of "running-out", supplied additional conjectures regarding the causal agent.

Early observations disclosed that the yield from virus-affected potatoes was 25 to 60 percent lower than that from healthy seed potatoes. This loss in yield indicated the importance of conducting investigations on potato virus diseases. About 1917, when intensive studies on potato virus diseases were begun by this Bureau, many potato fields in important seed-potato-producing areas manifested 50 to 100 percent mosaic-affected plants, and a considerable number of fields had over 50 percent of the plants infected with several virus diseases, resulting in dwarfed, curled, mottled, rolled, and streaked plants. Later this condition was found to be caused by composite infection with leaf roll, spindle tuber, and different mosaic viruses.

Inoculations by means of leaf-rubbing and grafts showed that different varieties did not necessarily react the same to the same disease. This experience led to the use of a single variety, the Green Mountain, as host for studies on virus isolation and identification.

As aphid transmission had been demonstrated for mosaic in tobacco, spinach, and cucumber, studies with potato aphids were made in the greenhouse and under cloth cages in the field. These studies disclosed for the first time that potato mosaic, leaf roll, and spindle tuber were transmitted by aphids. Comparative studies on the transmitting potency of Myzus persicae, M. circumflexus, M. solani, and Macrosiphum solanifolii disclosed that all four aphid species transmitted leaf roll, rugose mosaic, crinkle mosaic, and mild mosaic, but M. solanifolii was less effective as a vector of leaf roll than the other three species. Observations showed that M. solanifolii fed much less consistently in the vascular tissues than did the other species, which circumstance may be related to efficiency in transmission of leaf roll.

These potato virus infection studies revealed composite infection, i.e., mosaic + leaf roll + spindle tuber and mosaic + necrosis, as well as apparently single-virus infections. From the apparently single-virus infections, isolation plant cultures were propagated under insect-proof cages.

The performance of these isolation cultures, as well as of comparative single-virus plant selections from the field, revealed, upon propagation in isolation under cloth cages, that mosaic-affected plants did not deteriorate progressively from year to year, but remained stable, which was contrary to the former view.

Furthermore, the isolation studies led to the recognition of mild mosaic, leaf-rolling mosaic, and rugose mosaic, and later latent mosaic in the Green Mountain variety. When healthy seedling potato varieties were grafted onto apparently healthy Green Mountain most of them manifested foliage and apical stem necrosis, which showed that the apparently healthy Green Mountain harbored a mosaic virus, and this was termed latent mosaic. It was further determined that latent mosaic was a component of each of the mild, leaf-rolling, and rugose mosaic viruses. Under the system of designating potato viruses by using letters, latent mosaic is caused by virus X, mild mosaic by viruses A + X, and rugose mosaic by viruses X + Y.

An interesting abnormality of potato distinguished by "staring", sparse, erect, and somewhat dwarfed tops and typically spindle-shaped tubers, regarded by some observers as "physiological degeneration", was shown for the first time to be transmissible by grafting, leaf rubbing, and insects. The typically spindle-shaped tubers suggested the name spindle tuber for this potato virus disease.

The identification of spindle tuber as one of the potato virus diseases led to an understanding of certain so-called curly-dwarf potato plants that resulted from composite infections of spindle tuber +mosaic + leaf roll, as well as from dwarfing strains of the spindle tuber virus.

In connection with the studies on potato leaf roll an internal tuber discoloration termed net necrosis was identified as a tuber reaction to the leaf roll virus, which developed only in certain varieties, like Green Mountain, and only as a result of current-season infection of healthy plants with the leaf roll virus. It materially adds to the potato losses due to severe reductions in yield that result from leaf roll attack.

Anatomical studies on internal necrosis of potato disclosed that necrosis was associated with more than one disease. Necrosis is a diagnostic symptom of potato leaf roll when restricted to the phloem and occurring in stolons, tubers, and the tops of the plants.

Effect on Yield. -- Studies showed that mild mosaic reduced the yield of Green Mountain 25 to 30 percent; rugose mosaic reduced it 50 to 70 percent; spindle tuber, 30 to 35 percent; and leaf roll, 50 to 70 percent. The common race of the latent mosaic virus reduced yields 10 to 25 percent in some varieties. Since latent mosaic is generally harbored by the leading old varieties and by some of the new ones, it is reasonable to say that in the absence of latent mosaic yields would be increased at least 10 to 15 percent.

Isolated Seed Plots, and Early Harvesting. -- Insect transmission studies of potato virus diseases indicated that selection of apparently healthy hills in close proximity to virus-affected hills did not necessarily result in healthy seed potatoes, and that the percentage of healthy progeny increased as the distance from diseased plants was increased. This experience led to the use of isolated tuber-unit seed plots for control of potato virus diseases.

The tuber-unit method of planting facilitates detection of disease and the roguing of diseased hills. Studies on isolated tuber-unit seed plots located at different distances from virus-affected potato fields showed that when aphids were numerous, viruses spread to seed plots located several hundred feet from virus-affected potatoes, whereas healthy potatoes propagated in seed plots surrounded by woods and located a mile or more from diseased potatoes remained healthy.

Early harvesting of healthy plants from seed plots was initiated after experience had shown that roguing tuber-unit seed plots located within 1,000 feet of virus-affected potatoes did not insure 100 percent virus-free potatoes, though it did maintain the virus content in such rogued plots below 5 percent, whereas non-rogued fields of the same variety showed over 50 percent of virus diseases.

Harvesting tubers from apparently healthy hills located near virus-infected plants by taking one tuber from the same hill at weekly intervals from early in August to the middle of September had shown earlier that the earliest harvested tubers remained relatively free from disease, while the later harvested tubers produced many virus-diseased plants. This experience showed that virus infection of healthy plants increased as the season advanced.

In tests in Maine from 1932 to 1947, two varieties highly susceptible to virus diseases remained free from virus diseases when harvested about August 1, even though growing within 500 feet of diseased potatoes. Samples of these varieties harvested from the same plots September 15 developed 90 to 95 percent of mosaic and leaf roll in seasons when heavy aphid populations prevailed. This experience shows that susceptible potato varieties can be maintained free from virus diseases in some seed-potato-producing areas, even with meager isolation, if the seed potatoes are harvested very early in the season before the dispersal of virus-carrying aphids begins.

Varietal Resistance. -- Studies disclosed that different potato varieties vary in their reaction to the same virus disease. Some varieties react to the mosaic viruses by manifesting distinct mottling; others by slightly light green and rugose foliage; others by necrosis; and still others are carriers without apparent symptoms. Some varieties are highly resistant, while others are immune from certain mosaic viruses. The earlier field observations on mosaic in commercial varieties disclosed that the Green Mountain manifested a materially higher percentage of mosaic plants than Irish Cobbler. Inoculations with mild mosaic by means of aphids and leaf rubbing later showed that Irish Cobbler is immune from the virus A component of mild mosaic.

While studying the reaction of different varieties to the mild, rugose, and latent mosaics it was discovered that one of the potato seedling varieties contracted viruses A and Y, components respectively of mild and rugose mosaic, but did not contract virus X, the cause of latent mosaic. Subsequent studies with this seedling proved it to be immune from virus X, which is harbored generally by the older and some of the newer potato varieties.

Different varieties vary in their reaction to virus A component of mild mosaic as follows: distinctly mottled; slightly rugose and light green; top or apical necrosis; carriers with no apparent symptoms; those that contract infection more easily than others; and immunity. The varieties immune from virus A apparently fall into two groups: (1) Varieties that are immune by aphid infection but contract the virus by graft infection and produce mottled leaves, and (2) Varieties that are immune by aphid infection but in grafts develop necrotic local lesions, a hypersensitive reaction, where virus A apparently is inactivated.

Investigations on the reaction of varieties to virus X, the other component of mild mosaic, have disclosed that varieties differ in their reaction as follows: foliage mottling; slightly rugose and light green; necrosis; carriers with no apparent symptoms; and graft-immune; as well as immune with other methods of inoculation, including contact with plants harboring virus X.

In grafts aerial tubers form on a scion harboring virus X growing on a stock immune from virus X, which indicates that carbohydrates as well as virus X are unable to pass from the infected scion into the immune stock. This aerial tuber reaction facilitates isolation of varieties immune from virus X in segregating progenies.

By using jimson weed, Datura stramonium, and other host plants it has been found that there are several races of virus X, as determined by their reaction on the host. The weak race induces apparently no perceptible reaction; the so-called more virulent races induce severe necrosis; whereas the intermediate races induce various degrees of mottling.

Protective inoculations have shown that a potato plant inoculated with one race of virus X is protected against infection by other races. Inasmuch as varieties that are very susceptible to virus X readily contract infection when exposed to varieties harboring the virus in commercial fields, such new varieties susceptible to virus X can be protected against infection from the more severe races if they are inoculated with the weak race, which apparently affects the yield less. Experience in 10 consecutive seasons has shown that a variety harboring weak virus X and growing in alternate hills with potatoes harboring a stronger virus X race did not contract a stronger race of virus X, whereas the virus-free controls contracted it in every plant or hill.

Investigations have shown that a variety immune from virus X is immune from all the races of virus X so far tested.

Studies on the reaction of different varieties to virus Y, a component of rugose mosaic, disclosed that many varieties react by developing foliage necrosis, manifested by necrotic spots on the leaves and necrotic streaking of veins, petioles, and stems, which is associated with brittleness and leaf drop; rugosity and a vein-clearing type of mottling also appear on some varieties, along with the foregoing reactions; some varieties manifest light green and rugose foliage to so slight a degree that they may be mistaken for healthy plants.

Varieties immune from virus Y have not been found, but some varieties are highly field-resistant, i.e., rarely contract virus Y; whereas other varieties under the same conditions become 100 percent diseased.

The isolation, identification, and methods of inoculation of potato viruses and studies on the reaction of different potato varieties to different types of mosaic viruses, spindle tuber, and leaf roll viruses facilitate the program for breeding potatoes for resistance to virus diseases. As a result of this breeding work, potato varieties have been developed that harbor immunity from two major mosaic viruses and high field resistance to a third important mosaic virus. Moreover, some varieties immune from mosaic also are highly field-resistant to the other two important mosaic viruses, as well as to leaf roll. For instance, Katahdin, the first variety named under the National Potato-Breeding Program, is immune from virus A and field-resistant to viruses X and Y and to leaf roll. Chippewa, the second variety named under this program, is immune from virus A and very highly field-resistant to virus Y.

The use of these varieties immune from mosaic, together with other resistant varieties, has contributed towards progress in potato production and improvement and has facilitated control of important potato mosaic diseases.

SUMMARY OF ACCOMPLISHMENTS IN POTATO DISEASE INVESTIGATIONS BY THE BUREAU OF PLANT INDUSTRY, SOILS, AND AGRICULTURAL ENGINEERING, 1910 to 1949:

1. In 1911, W. A. Orton was impressed by the results of seed-potato inspection and certification in Germany during his visit to that country. He succeeded in initiating seed-potato certification in the United States through conferences with State representatives of the potato industry and through publications. Undoubtedly seed-potato certification ranks first among the agencies that induce growers to produce disease-free seed potatoes.

2. Studies on powdery scab showed that the disease was favored by environmental conditions in certain northern potato areas but it was not a limiting factor in southern potato regions; and that soil and seed-potato treatments did not entirely inhibit this disease.

3. Investigations on hibernation of the late blight fungus disclosed that infected tubers harbor the late blight mycelium which invades the young shoots, on which the fungus sporulates and thus initiates infection of potato fields. These results confirmed de Bary's observations on the perennial mycelium that had been questioned by later workers. Potato cull piles with tubers infected with late blight were found to be major reservoirs for initial infection of commercial potato fields. Investigations show that blight-immune varieties can be developed, and that, as other workers found, the late blight fungus represents several races, so that an apparently blight-immune variety is not necessarily immune from all races of the late blight fungus.

4. Studies on resistance of potatoes to common scab disclosed that certain varieties are highly resistant to this disease.

5. Studies on resistance of potatoes to bacterial ring rot have disclosed that certain varieties are highly resistant to this disease.

6. Studies on potato wart disclosed that intermittent flooding and aeration are most favorable for spore germination; with variable soil temperature, infection occurs when the mean is about

21° C.; the most favorable soil reaction range is about pH 3.9 to pH 8.5; and that on the basis of resistance, potato varieties that fall into the same natural group react similarly to wart. In general, the Irish Cobbler, Spaulding Rose, McCormick, Burbank, and Green Mountain types are wart-immune, whereas the Triumph, Early Rose, Early Ohio, Rural, Pearl, American Giant, and Up-to-Date are susceptible.

7. Studies on potato tuber rots disclosed that cuts, bruises, skin abrasions, sunscald, freezing injury, and late blight infection predispose potato tubers to decay-producing organisms and that careful handling during harvesting, storing, transporting, and marketing to prevent mechanical injury is very essential for preventing tuber rots.

8. Experience with seed-potato treatments for control of tuber surface-borne diseases has shown that corrosive sublimate and certain organic mercuries controlled Rhizoctonia canker; treating seed potatoes that were heavily infected with Rhizoctonia significantly increased the yield; in some seasons seed-potato treatments controlled seed-piece decay; and treating clean seed potatoes had no adverse effect on yield.

9. Studies on so-called deterioration, or running-out, of potatoes showed that mosaic or leaf roll or combinations of these diseases, sometimes involving as high as 50 to 100 percent of the plants, were primarily responsible for potato deterioration.

10. For the first time inoculations by leaf rubbing, grafting, and aphids resulted in transmitting potato mosaic, whereas only grafting and aphids were effective in transmitting leaf roll.

11. Isolation, identification, and cultural studies with potato mosaic revealed that mosaic was not caused by a single virus that gradually reverted to more severe forms, but was a composite of several viruses.

12. Different potato varieties were found to give different reactions to the same mosaic virus, which indicated the necessity of using a single variety to identify and classify mosaic viruses.

13. A type of potato disorder characterized by erect, sparse, "staring" tops, and spindle-shaped tubers was shown to be a virus disease and was named spindle tuber. Spindle tuber in conjunction with certain mosaic viruses and leaf roll was found to be causatively associated with certain so-called curly-dwarf types of potato virus diseases.

14. Experience with selection of apparently healthy potatoes at different distances from virus-affected potatoes showed that the percentage of plants contracting virus infection decreased the farther they were from the diseased plants. This suggested the use of the tuber-unit isolated seed plot for control of virus diseases through use of clean seed.

15. Results from harvesting potatoes at different dates during the season showed that the percentage of virus infection increased with the advance of the season and suggested early harvesting of seed potatoes.

16. When virus-susceptible potatoes located within 500 feet of diseased potatoes were harvested about August 1 in Maine they were maintained free from virus diseases from 1932 to 1947.

17. Experience with the reaction of different potato varieties to mosaic showed that they vary in their symptomatology as well as in their resistance. Certain varieties are immune from some one of the three more common mosaic viruses A, X, and Y, but are susceptible to the other two mosaic viruses.

18. Varieties have been developed that are immune from virus A, as well as field-resistant to viruses X and Y and to leaf roll; some are immune from virus X; and others are highly field-resistant to virus Y.

19. Studies on isolation, identification, classification, inter-varietal reaction, and transmission of potato viruses have been essential in selecting and breeding potatoes for resistance to the various diseases.

20. Potato disease investigations have helped in the production of varieties resistant to major virus and fungus diseases, and work is in progress designed to develop a variety that has combined resistance to the major potato diseases and in addition has desirable horticultural characters.

21. The results obtained from investigations on potato diseases in the Bureau of Plant Industry, Soils, and Agricultural Engineering, United States Department of Agriculture, 1910 to 1949, are recorded in more than 200 publications, including technical bulletins, farmers' bulletins, circulars, and research journals. They contribute toward an understanding of the nature, life history, transmission, identification, and disease resistance and other methods of control of the major potato diseases. This information materially contributes toward increased yields and reduced waste and losses in harvesting, storage, transportation, and marketing, which serves to place the potato industry on a fundamentally sound economic basis.

DIVISION OF FRUIT AND VEGETABLE CROPS AND DISEASES, BUREAU OF PLANT INDUSTRY, SOILS, AND AGRICULTURAL ENGINEERING

FIELD AND LABORATORY RESEARCH ON THE DISEASES OF HARDY FRUIT CROPS CONDUCTED BY THE UNITED STATES DEPARTMENT OF AGRICULTURE 1885-1950[1]

John C. Dunegan

INTRODUCTION

The need for investigations on the diseases of fruit crops was one of the first problems confronting the newly established Section of Mycology organized on July 1, 1885 in the Botanical Division of the Department of Agriculture, with F. L. Scribner as the first mycologist. During the 65 years which have elapsed since this section was established many fruit diseases have been investigated and, for the most part, satisfactory control measures developed, but some old and other newly discovered diseases continue to be serious threats to fruit production in the United States.

In reviewing the varied investigations on fruit diseases by Department workers over the 65-year period, it seems best to divide this period roughly into a series of decades and discuss the work and results which characterized each decade.

THE PIONEER PERIOD 1885-1900

At the present time, when fruit pathologists are greatly concerned with the virus diseases affecting deciduous fruit crops, it is interesting to note that Erwin F. Smith in 1886 was assigned the problem of investigating the destructive malady known as peach yellows. Thus, one of the first problems investigated in the Department on fruit diseases dealt with a virus disease and the paper published in 1888 by Smith on peach yellows still is one of the most comprehensive descriptions of this disease that we have. A second paper published by Smith in 1891, under the title "Additional Evidence on the Communicability of Peach Yellows and Peach Rosette," gave detailed information on the contagious nature of peach yellows and peach rosette, another disease which had been confused with peach yellows.

In 1889 Scribner was succeeded by B. T. Galloway who gathered around him a staff of young, competent, and enthusiastic investigators. One of these men, N. B. Pierce, published in 1900 a monographic study of another peach disease under the title "Peach Leaf Curl, Its Nature and Treatment." In this bulletin Pierce presented the results of his experiments which demonstrated conclusively that peach-leaf curl (Taphrina deformans) could be successfully controlled by dormant applications of either lime-sulfur or bordeaux mixture.

M. B. Waite, who joined Galloway's staff at this time, started his career of more than 40 years in Government service by investigating pear blight (Erwinia amylovora), a bacterial disease of pears and apples. He found that the disease was spread by insects depositing bacteria in the nectar of pear blossoms. Since this was the first demonstration of the insect transmission of a bacterial disease of plants, Waite gained international renown through this discovery.

Waite continued his study of the disease as it occurs in orchards in many parts of the country and by 1895 concluded that the only practical method of controlling the trouble was to cut out and burn every particle of blight when the trees were dormant, stating, "Not a single case of active blight should be allowed to survive the winter in the orchard, or within a half-mile or so of it." This removal of the source of overwintering bacteria is an arduous and expensive procedure but growers in the Pacific Coast States have adopted Waite's method and have been able to produce crops of pears for many years. The entire western pear industry stands as a monument to this fundamental work of M. B. Waite.

THE SECOND DECADE 1900-1910

By 1900 work in plant pathology was a well-established function of the Department of Agriculture and the staff was being organized on a more specialized basis. Waite was placed in charge of the Office of Fruit Disease Investigations and he, like Galloway in the preceding decade, enlisted a group of capable, young investigators. With the staff increased, the tempo of work was accelerated and diverse problems were attacked with the development of practical control procedures as the ultimate goal.

One of the major problems which confronted the staff in 1900 was the development of a satisfactory fungicide for use on peach trees during the growing season. The fungus diseases brown rot (Monilinia fructicola), and scab (Cladosporium carpophilum), were limiting factors in peach

[1] Problems associated with the transportation and storage of hardy fruit crops are not considered in this summary.

production; yet, when the growers attempted to control these diseases with bordeaux mixture, their efforts frequently resulted in excessive injury to the trees. The fungicidal properties of sulfur had been recognized prior to 1900 but the only spray preparation then available was liquid lime-sulfur solution, which often severely injured peach leaves and twigs when used during the growing season. In 1901 W. M. Scott, working with M. B. Waite, tested a series of sulfides but found that they, too, were extremely caustic. Within a few years, however, Scott was experimenting with a mixture of sulfur and stone-lime in which small quantities of water were added to the stone-lime. The heat resulting from the slaking of the lime produced a chemical reaction with the sulfur. Additional water was added, stopping this reaction before injurious calcium polysulfides were formed, with the result that an effective mixture of sulfur and lime was produced which was not injurious to peach foliage. Scott, in his original description of self-boiled lime-sulfur, notes that as early as 1833 a Dr. William Kendrick had prepared a crude form of this fungicide and had recommended it for the control of mildew on grapes, and that in 1885 William Saunders had produced a similar material by mixing sulfur and lime with boiling water, but it remained for Scott to demonstrate that an effective and safe summer-fungicide for peaches could be prepared through the use of stone-lime and sulfur. A preliminary account of these experiments with self-boiled lime-sulfur was published in 1908, and in 1910 Scott and T. W. Ayres published a full account of their experiments with self-boiled lime-sulfur. The marked control obtained with self-boiled lime-sulfur over the brown rot fungus and the peach scab fungus without producing injury gave a decided impetus to the commercial production of fresh peaches in the humid, eastern sections of the United States. In fact, the extensive plantings of peaches from Georgia to as far north as Michigan, New York, and Massachusetts were made possible only by this fundamental discovery.

In 1902 Erwin F. Smith announced the discovery of the new bacterial disease of Japanese plums in Michigan which he called the black spot disease. He isolated the organism in pure culture and was able to reproduce the disease by spraying suspensions on young, green plums. About this time numerous State investigators in the East were finding a disease on peaches likewise caused by a yellow bacterial organism but the symptoms on the fruit were not similar to those produced on plums by the organism Smith had discovered. The symptoms on the leaves, a typical leaf-spot effect, however, were quite similar and it seemed possible that the organism originally described on plum was also a serious parasite of the peach. J. B. Rorer, another investigator Waite had added to his staff, attacked this problem and by 1908 he was in a position to state that the organisms (now known as Xanthomonas pruni) attacking the plum and the peach were identical.

In 1905 Waite, while studying pear blight in California, had his attention called to a disease of peaches, almonds, and apricots producing a gummosis of the twigs and the death of many buds. This disease, caused by the fungus Coryneum beijerinckii, had been seen as early as 1898 in specimens from Ohio and had been mentioned by Pierce in his discussion of peach-leaf curl as being present in California. The production in some of the most profitable orchards had been reduced to one-half or even a quarter of the crop. Since this disease seemed most aggressive during the dormant period when the leaves were off the trees, it had been suggested that bordeaux mixture should be employed as a fungicide to control the trouble. California growers, however, reported that bordeaux mixture was quite ineffective, but upon questioning them, Waite found that the sprays were not applied until after the disease began to appear on the twigs. He immediately suggested that they apply the sprays in the late fall or very early winter before the disease became evident. He reported in 1906 that orchardists who had sprayed their blocks of peach trees with bordeaux mixture, in December 1905, stated in March of 1906 that there was no evidence of the disease in any of the trees even though one of the orchards had been severely injured in 1905. Furthermore, the growers left non-treated blocks and the disease in these blocks was even more severe than it had been in 1905. This demonstration of the proper time to use a well-known fungicide has been of fundamental importance to the growers of almond, peaches, and apricots in the Pacific Coast States.

Not all the work of the Office of Fruit Disease Investigations was confined to the investigation of peach diseases, for during this period Scott investigated the control of apple blotch (Phyllosticta solitaria) and apple bitter rot (Glomerella cingulata), two serious fungus diseases of apple orchards. Since self-boiled lime-sulfur had proved so effective for the control of peach brown rot and scab, it seemed obvious that the same materials should be tried for the control of apple diseases, but it was soon found that this material was only moderately effective against these apple diseases. It was also demonstrated that liquid lime-sulfur solution, which was effective against the apple scab fungus, did not yield satisfactory control of either the blotch or the bitter rot fungi. However, Scott, in a series of experiments conducted in Arkansas and other midwestern states, demonstrated that bordeaux mixture could be used for the control of these two diseases and he devised a spray schedule in which the use of bordeaux mixture was avoided in the early applica-

tions, thus reducing the amount of fruit russetting. Bordeaux mixture gave outstanding control results against these two fungi, but in some seasons and with certain varieties there was apt to be considerable russet of the fruit even when used as recommended by Scott. Elimination of russet due to the use of bordeaux mixture and the reduction of foliage injury from this same material was to prove to be a very vexing problem and the solution was not reached in the matter of copper injury until several decades later.

Fungus diseases and fungicides were not the only problems investigated by members of the Department dealing with fruit diseases during this interval. Waite, for example, began an extensive study of the effect of low temperatures on fruit trees. Some of his observations, published under the title "Fruit Trees Frozen in 1904," have been most helpful to growers who have had recurring low-temperature injury. One of the most fundamental concepts derived from this study of low-temperature injuries is the fact that trees injured during the winter are in what might be called a state of "shock" and should not be pruned immediately after the injury.

This interest in low-temperature injury to fruit trees became one of the abiding interests of Waite throughout the balance of his professional career and he was one of the first to suspect that the premature death of peach trees in the southern orchards was due to what he called the "southern type of winter injury." Waite noted that in the South there were marked fluctuations in the temperature during the winter with periods of 70° to 75° F. followed by abrupt drops within a few hours to temperatures below freezing. Under the influence of the high temperatures which frequently prevailed for several weeks in midwinter, cambial activity was started and drastic injury resulting in the death of many trees was the aftermath of the sudden drops in temperature.

W. M. Scott, after a series of experiments with self-boiled lime-sulfur for the control of apple diseases, instituted a series of experiments using lime-sulfur solution as a substitute for bordeaux mixture in the control of the apple scab fungus (Venturia inaequalis). A. B. Cordley, R. K. Beattie, E. Wallace, and C. Brooks reported that dilute lime-sulfur solution had given them good control of the apple scab fungus in the particular States where they were working. Since the use of bordeaux mixture early in the season is generally accompanied by pronounced russetting of the young apples, Scott and the other workers were very anxious to secure a substitute which would eliminate this injury. He reported in 1910 that liquid lime-sulfur solution could be satisfactorily substituted for bordeaux mixture in the treatment of apple scab and for the apple leaf spot commonly associated with the black rot fungus (Physalospora obtusa). It was soon noted, however, that liquid lime-sulfur will also produce, under certain conditions, injury to the leaves and at times even a sulfur-burning of the fruit. The problem of reduction of injury from liquid lime-sulfur continues to be a vexing problem even at the present time.

The cherry leaf spot fungus, Coccomyces hiemalis, producing a disease of the leaves which results in premature defoliation and even the death of the trees if allowed to continue for several years unchecked, was another problem which attracted Scott's interest during this decade. Among the materials which he tested were dilute lime-sulfur solution, self-boiled lime-sulfur, and bordeaux mixture. Some of his experiments with self-boiled lime-sulfur gave satisfactory control of the leaf spot fungus but continued experimentation demonstrated that either dilute liquid lime-sulfur or bordeaux mixture were the most satisfactory materials to use. Here again, the problem of injury from the use of fungicides was noted and it was soon discovered that bordeaux mixture could not be used with safety on sweet cherries, and under some conditions, lime-sulfur solution produced injury to the foliage.

C. L. Shear began his study of the fungus diseases of cranberries and published his first report on them in 1907.

Thus the decade 1900-1910 was one of marked progress. The scientific staff was expanding in the Department of Agriculture and pathologists had attacked with vigor problems of peach disease control, such as brown rot and scab; and apple diseases, such as apple scab, leaf spot, blotch, and bitter rot. They had experimented with a variety of fungicides, had devised a new form of self-boiled lime-sulfur, had worked out a method for the control of pear blight in the West, had demonstrated that Coryneum blight could be controlled by dormant spraying, had gained insight into the fundamental problems of response of fruit trees to low temperatures, and had shown that there was in the East a serious disease of peaches of bacterial origin. These achievements must be classed as outstanding, but at the same time, they had encountered the problem of spray injury. It was not sufficient, they found merely to control the fungus disease attacking fruit trees, but the control should be with materials that were relatively noninjurious to the host plant. Their solution of this vexing problem was not satisfactory and the matter of reduction of injury with the use of fungicides was one that was to attract the attention of Department and State investigators for many years to come.

THE THIRD DECADE 1910-1920

The outstanding results of the preceding decade served as a further stimulus to the work of fruit pathology in the Department and new additions were made to the staff, while some of the older workers left the Department to engage in other lines of activity.

During this period John W. Roberts demonstrated that the apple leaf spot, commonly called frogeye, was the result of an initial infection of the leaf by the black rot fungus followed by invasion of the dead tissue by weak parasites, particularly a species of Alternaria. He showed further that typical frogeye spots could be produced artificially by killing a small spot of leaf tissue and the Alternaria promptly invaded the dead tissue. This discovery made it clear that apple leaves injured by spray chemicals could subsequently develop a series of typical frogeye leaf spots even though there was little or no black rot present in the orchard.

Working in Arkansas, Roberts also investigated the problem of the overwintering of the apple bitter rot fungus and found that in orchards where the fungus was causing complete loss of the crops season after season it produced typical cankers on the twigs and smaller limbs. Subsequent investigators have been unable to find these bitter rot cankers, but it must be remembered that the majority of the orchards in recent years have been sprayed with bordeaux mixture and do not represent conditions similar to those studied by Roberts where the fungus had been allowed to grow unchecked over a period of years in the orchard.

Roberts also studied in Arkansas methods for the control of the peach bacterial disease which had been described by Rorer. He noted that the disease was most serious on trees in a poor state of vigor, or those growing in soils low in fertility, and he demonstrated that the disease could be held in check by proper cultural procedures and the judicious use of nitrogen fertilizer.

During this period G. W. Keitt, now at the University of Wisconsin, carried on extensive studies at Hart, Michigan, and Cornelia, Georgia, on the peach scab fungus. His monographic study appeared as a Department bulletin in 1917 and has long been accepted as a classic on the subject. One of the most important features of Keitt's study was the demonstration that the scab organism grows very slowly. The infections take place from 50 to 60 days before the spots become visible, and he showed that for proper control the first spray application should be made about one month after the petals have dropped. This is long before any symptoms of the disease appear on the fruit; but the commercial growers, universally, have accepted this finding and an application for control of peach scab early in the season is a standard procedure.

Shear discussed in 1915 the prevalence of grape anthracnose in the United States, and L. A. Hawkins reported the same year that the disease could be controlled by the use of a dormant spray of lime-sulfur followed by 4 or 5 applications of 8-8-100 bordeaux mixture during the growing season.

N. E. Stevens studied the correlation between climatic conditions and the prevalence of cranberry fruit rots in the United States, while Shear described an end rot of cranberries due to Fusicoccum putrefaciens, as well as false blossom disease of cranberries.

D. F. Fisher, W. S. Ballard, and W. H. Volk studied the control of apple powdery mildew in western fruit-growing districts. They found that the arid climate favored the development of the fungus Podosphaera leucotricha, and that the disease could be effectively controlled by the use of dilute lime-sulfur during the growing season. However, the use of this material in western orchards after the first of June was almost certain to cause severe injury to the fruit.

Shear, Stevens, R. B. Wilcox, and B. A. Rudolph investigated the fungi causing fruit rot after the cranberries were harvested.

Stevens continued his studies on fruit rots with a study of the pathological histology of strawberries affected by a species of Botrytis and Rhizopus.

THE DECADE 1920-1930

A serious outbreak of brown rot and plum curculio in the Fort Valley peach area during the 1920 season led to the establishment, in 1921, of a field laboratory at Fort Valley, Georgia. Extensive experiments for the combined control of brown rot, scab, and curculio were carried on during the years 1920 to 1924 by the Bureau of Entomology, Bureau of Plant Industry, and the Georgia State Board of Entomology. The writer was assigned to work at Fort Valley in 1921 on peach brown rot, scab, and bacterial spot. L. M. Hutchins also started his extensive studies at Fort Valley on the phony disease of the peach, as well as his studies on the southern type of winter injury and the delayed dormancy problem.

During this time Roberts and Dunegan initiated experiments on the control of blossom blight (Monilinia) and found that it would be necessary to apply a series of sprays during the blossom

period for satisfactory control. Later work demonstrated that this original concept of the blossom blight control problem was essentially sound, but in the early '20s spray machinery was not available for the rapid application of sprays over extensive areas and the program was abandoned at that time as being impractical.

At this time extensive peach plantings were coming into bearing in the Sandhill region of North Carolina and it soon became evident that the cultural procedures and the use of nitrogen fertilizers for bacterial spot control, as recommended by Roberts in the preceding decade, would not yield satisfactory results in North Carolina. Roberts started experiments which eventually led to the development of the zinc-lime spray, prepared by adding a dilute solution of zinc sulfate to a dilute solution of hydrated lime.

In a series of experiments at Vincennes, Indiana, Roberts and Leslie Pierce demonstrated that zinc-lime spray, carefully applied with particular emphasis on covering the underside of the leaves, would give a degree of control of the bacterial spot organism, both on the leaves and fruit, better than anything that had been previously tested. The final program required between five and seven spray applications made at intervals of two weeks. This was an arduous spray program, but the results were so outstanding in Indiana and elsewhere that the growers accepted the program and put it into commercial operation in many parts of the country.

With the termination of work on the brown rot problem at the Fort Valley laboratory, Dunegan began a study of the life cycle of the bacterial spot organism under Georgia conditions. Roberts and Dunegan also summarized the results of their studies on the life cycle and taxonomy of the peach brown rot fungus in the United States.

Another problem which was studied at the Fort Valley laboratory was the prevalence of the rust fungus, Tranzschelia pruni-spinosae, on peach foliage and its relation to a rust which was equally prevalent on wild plum and wild cherry trees.

During this period B. O. Dodge began his comprehensive studies of the rust fungi attacking various species of Rubus and showed that there were long-cycle and short-cycle forms. He found an intermediate form which he believed represented a new species being evolved from a long-cycle form. Dodge's papers were replete with cytological details and many comments upon the evolution of the fungi.

In addition to these investigations, Dodge studied the systemic infection of Rubus plants and suggested control measures based on his findings. Working in cooperation with F. A. Wolf in North Carolina he also demonstrated that anthracnose (Elsinoë veneta) of dewberries could be controlled by spraying the vines with bordeaux mixture.

Dodge also demonstrated that a blight of raspberries was due to a fungus that could not be distinguished from the fungus causing bitter rot of apples. This disease described by Dodge was distinct from the common anthracnose (Elsinoë) disease of raspberries which Shear stated was caused by a fungus closely related to, but distinct from the fungus causing the "bird's eye" rot of grapes.

Shear and H. F. Bain described the perfect stage of the fungus causing the stem-end rot of cranberries. This fungus, Godronia cassandrae, was first described by Shear in 1917 as Fusicoccum putrefaciens.

Other work during this period included the description by Angie M. Beckwith of the life cycle of the grape root-rot fungus, Roesleria hypogea; the suggestion by R. B. Wilcox that the eastern blue-stem disease of black raspberry was a virus disease; the studies by H. F. Bergman on the respiratory activities of various parts of the cranberry plants as well as the oxygen content of bog water; the description of leather rot of strawberries due to Phytophthora cactorum by D. H. Rose; and the description by Dodge and Stevens of the Rhizoctonia brown rot of strawberries, the Botrytis gray mold, and the tan rot due to Pezizella lythri.

In 1928 a reorganization program in the Department of Agriculture led to the fusion of the horticultural and pathological staffs. The Office of Fruit Disease Investigations became a part of the new Office of Horticultural Crops and Diseases under the leadership of E. C. Auchter.

THE DECADE 1930-1940

During this period further reorganization in the Department of Agriculture led to the formation in 1932 of the Division of Horticultural Crops and Diseases. E. C. Auchter was the first leader of this new Division and when he was assigned to other duties, H. P. Gould assumed this responsibility in 1938.

The problem of spray injury from liquid lime-sulfur and bordeaux mixture, which had been noted from time to time in the accounts of the previous decades, became increasingly important with the education of the public to demand high-quality fruit, and at the very beginning of this decade a new project was organized for the purpose of devising other fungicides which would give

control equal to that obtained with the standard liquid lime-sulfur and bordeaux mixture, but would be less injurious to the host plants. M. C. Goldsworthy and E. L. Green joined the staff in 1930 and started studies of fungicides on a combined chemical and pathological basis. They produced a series of copper compounds, such as copper silicate, copper oxide silicate, copper phosphate, and also began to investigate the possibility of the use of dithiocarbamates as fungicides. They also developed a screening procedure which combined a laboratory test of the toxicity of the fungicide to the spores of certain fungi, a study of the effect upon the material of exposure to outdoor conditions for periods varying from one day to two weeks, and a test of the phytotoxicity of the material on peach and apple leaves.

Materials which proved promising in the screening tests were then subjected to small-scale spray experiments, and if the results continued promising, the following year fairly large-scale, field-spraying tests were started at Vincennes, Indiana, and in the vicinity of Fayetteville, Arkansas, as well as in the orchards of the Plant Industry Station at Beltsville.

During this decade much of the work in the field-spraying experiments was devoted to the investigation of new compounds. While none were found that were completely satisfactory as substitutes for either liquid lime-sulfur or bordeaux mixture, the negative results which were obtained were valuable in that they eliminated from further testing a great variety of inorganic compounds and cleared the field for intensive study of organic materials during the next decade.

During this period M. A. Smith, H. B. Johnson, and Dunegan observed an outbreak of a bacterial disease on English Morello cherries at Seymour, Missouri, and through cross-inoculation experiments were able to prove that the organism was identical with the one producing the bacterial spot disease of peach and plum.

Additional field-spraying experiments were instituted in cooperation with the Missouri Agricultural Experiment Station at the Fruit Experiment Station at Mountain Grove, Missouri, and for a number of years materials were simultaneously tested at Vincennes, Indiana; Fayetteville, Arkansas; and Mountain Grove, Missouri. As a part of this work Goldsworthy at Beltsville, and M. A. Smith at Mountain Grove, Missouri, carried on a study of the life cycle of the pear leaf spot organism, *Fabraea maculata*, and demonstrated that copper phosphate was an excellent material for the control of this organism and caused no injury to either the pear fruit or the foliage.

Shortly after his transfer in 1928 to Fayetteville, Arkansas, Dunegan found that the peach rust fungus, which had aroused his interest at Fort Valley, Georgia, was present in the Arkansas orchards and caused a premature defoliation similar to that which occurred in Georgia. It was also noted that the aecial stage on *Anemone carolinana* was extremely prevalent in northwest Arkansas and yet rust did not appear on wild plum and cherry or the peach until the end of the growing season. Inoculation experiments with aeciospores demonstrated that the cherry and wild plum leaves could readily be infected early in the spring but the aeciospores from *Anemone carolinana* would not infect peach leaves. It was found, also, that aeciospores on *Anemone coronaria*, an introduced species, would infect such cultivated species as plum and peach but would not attack wild cherry or wild plum leaves.

A series of cross-inoculation experiments and a study of herbarium specimens from all parts of the world demonstrated that these differences in aecial hosts could be correlated with differences in the morphological structure of the teliospores. It was concluded, therefore, that there were two distinct forms of the rust present not only in the United States but throughout the world; attacking on one hand, cultivated forms; and on the other, wild species of the genus *Prunus*.

Another problem studied at Fayetteville was the obscure disease known as apple measles originally described from northwest Arkansas orchards by J. L. Hewitt and H. E. Truax in 1912. A comparison of current specimens collected in northwest Arkansas with photographs and microscopic slides of the original material led to the conclusion that the disease Hewitt and Truax called "measles" was merely the symptoms produced by the deposition of leafhopper eggs in apple twigs. D. Isley, of the Department of Entomology of the University of Arkansas, assisted in this work. This discovery did not solve the apple-measles problem because other workers subsequent to Hewitt and Truax had included under the term "measles" a variety of obscure bark conditions which were not correlated with leafhopper egg-laying activities. The work in northwest Arkansas, however, made it clear that one form of injury, the only one to which, strictly speaking, the name "apple measles" should be applied, is caused by the deposition of the leafhopper eggs.

A stem-canker disease of peach seedlings in the nursery rows was studied in Arkansas and Missouri, and Dunegan reported that the disease was caused by *Phytophthora cactorum*.

In the Northwest E. V. Miller in 1932 and J. R. Kienholz in 1939 reported on their studies of the fungi causing apple anthracnose and perennial canker, two diseases caused by closely related fungi. Kienholz found that copper fungicides were effective in the control of anthracnose (*Neofabraea malicorticis*) in the orchards but did not materially affect perennial canker (*N. perennans*) infections.

Kienholz also reported in 1939 the result of his studies on stony pit, an obscure disease prevalent on the Bosc and, to a lesser extent, on the Anjou, and other pear varieties in Oregon, Washington, and California. By means of budding experiments Kienholz proved that stony pit is a virus disease. Kienholz, working with Leroy Childs of the Oregon Agricultural Experiment Station, found that the pear scab (Venturia pyrina) organism overwintered on the twigs in Oregon. In seasons favorable to the development of the fungus these twig lesions greatly complicated the control problem.

Hutchins published in 1933 an extensive account of his studies on the phony disease of the peach and stated that the disease is caused by a virus which has an unusually long period of incubation (frequently two full season's growth). The virus, he found, could be readily transmitted by root grafting. In 1937 Hutchins, E. W. Bodine, and H. H. Thornberry described peach mosaic, a new virus disease of peach trees analogous to peach yellows in its contagious nature, rapidity of spread, and menace to the commercial peach industry.

Work of the Division on small fruits was not neglected during this period and in 1931 Stevens reported that since false blossom of cranberries had been found to be transmitted by leafhoppers, he considered one of the factors in the spread of this virus disease to be the replacement of native vines with susceptible varieties. In 1932 Stevens and P. V. Mook reported that strawberry dwarf was due to nematode infections (Aphelenchoides).

R. B. Wilcox and Angie M. Beckwith the following year, in studying the varietal resistance of cranberries to false blossom, found that in comparing varieties the cuttings must be of equal vigor and state of maturity if the comparison between varieties is to be valid.

E. A. Siegler carried on an extensive series of experiments in the control of crown gall (Agrobacterium tumefaciens) on apple nursery stock and reported, among other findings, that the addition of lime to the soil seemed to favor the development of the crown gall organism.

Shear, Stevens, and Bain published in 1931, as a revision of an earlier bulletin by Shear, a monograph on the diseases of cranberries in the United States.

Nellie A. Brown described galls on blueberry stems produced by a species of Phomopsis, while Marguerite S. Wilcox described in 1939 a twig blight of blueberries due to a species of Phomopsis distinct from the one described by Nellie A. Brown, and in 1940 found the perfect stage (a species of Diaporthe) of the blueberry twig blight organism.

J. B. Demaree,. I. Dix, and C. A. Magoon reported in 1937 the results of their studies on the resistance of 270 varieties of grapes to black rot (Guignardia bidwellii) and downy mildew (Plasmopora viticola). They found that 27 varieties were resistant to both fungi, 17 varieties were resistant to downy mildew but susceptible to black rot, and 63 were resistant to black rot but susceptible to downy mildew. Elmer Snyder, working in California, reported that most grape root stocks were susceptible to nematode attacks but a few varieties and their hybrids showed enough resistance to be worthy of further testing.

THE DECADE 1940-1950

H. P. Gould retired in 1941 and J. R. Magness assumed leadership of the Division of Fruit and Vegetable Crops and Diseases on October 1, 1941. Under his inspiring guidance the horticultural and pathological investigations have been further integrated and a closely knit unit working on all phases of fruit and vegetable problems has resulted.

In the field of disease control by spraying, much of the work from 1940 to the present time has been concerned with the development and testing of organic fungicide materials. One of the first materials to be used extensively was ferbam, or ferric dimethyldithiocarbamate, which was used extensively not only by members of the Department of Agriculture but by the various State agricultural experiment station workers. It soon became evident that ferbam was a promising compound since it was fungicidally active and yet produced practically no injury to the leaves and fruit of the apple. In seasons when the environmental conditions were not extremely favorable to the development of the scab fungus ferbam was found to be a satisfactory substitute for lime-sulfur. Experiments, started in Arkansas and subsequently repeated in Delaware, demonstrated that ferbam could be used very satisfactorily as a substitute for bordeaux mixture for the control of the apple blotch fungus; and at the same time, experiments in Arkansas and elsewhere had demonstrated that ferbam was an effective material to use for the control of the apple bitter rot fungus. Since no russetting of the fruit and no serious foliage damage accompanied the use of ferbam, it appeared that one of the objectives for which fruit pathologists had been striving for many years was at last attained; namely, a material that would replace copper and reduce, or practically eliminate, the damage caused by copper fungicides.

Ferbam likewise proved to be effective for the control of pear scab in the Pacific Northwest,

and Kienholz in Oregon demonstrated that this compound would control scab and not russet the high-quality pears which were grown in that area.

The introduction of ferbam was soon followed by the introduction by competing firms of other organic chemicals. One of these materials, Phygon (2, 3-dichloro 1, 4-naphthoquinone), proved to be exceptionally effective against the bitter rot fungus in experiments carried on in Arkansas, but it produced a peculiar type of epidermal spotting of the fruit and an irritation of the skin of some workers who used it as a spray or dust.

Goldsworthy and Green studied a series of the dithiocarbamate compounds and concluded that the dimethyl derivatives appeared to possess the greatest fungicidal value, and that among the metallic salts that could be combined with the organic radical, the iron, lead, and zinc salts were the most promising.

The development of organic fungicides was greatly accelerated during World War II by the shortage of copper and other chemicals resulting from the needs of the armed forces. Accompanying this shortage in materials there was also a shortage of human labor and many orchardists turned to mechanical methods of spraying trees, using booms and multiple-outlet units in order to attain, with the limited manpower, the same protection they formerly had obtained with the older methods of spraying.

The advent of the mechanical sprayer, reducing to a matter of a few days the spraying of extensive orchards, made it feasible to reconsider the problem of peach blossom blight control, since it had been found in the 1920 era that a fungicidal spray applied during the blossom period would give protection for about three days. During 1946-47-48, Goldsworthy, R. A. Wilson, and Dunegan tested the feasibility of applying sprays to peach trees at 3-day intervals during the bloom period and found that blossom blight could be materially reduced by three or four such blossom applications. The reduction in the amount of blossom blight was accompanied by a reduction of fruit rot at harvest time. This demonstration of blossom blight control and its relation to fruit rot represents the attainment of another goal which had been in the minds of Department workers for many years.

The problem of bacterial spot control continued to be one of the most serious of all the fruit disease problems. With the advent of organic materials, steps were taken immediately to determine whether or not any of these new preparations would be more efficient than zinc-lime for the control of this most troublesome disease. In cooperation with R. H. Daines, of the New Jersey Agricultural Experiment Station, a variety of materials have been tested in New Jersey peach orchards. Among these were Phygon, copper 8-quinolinolate, zinc-dimethyl dithiocarbamate, chlorine compounds, a variety of inorganic zinc salts, and also, during 1949, N-trichloromethyl thiotetrahydropthalimide, commonly called Orthocide 406. The results with the last named compound were promising in one series of experiments in New Jersey, but they could not be duplicated in the other series and further tests are in progress during the 1950 season. None of the other compounds were as effective as the zinc-lime spray. The control of this peach disease continues to be one of the unsolved problems.

In the Pacific Northwest a variety of organic materials and an antibiotic were tested for the control of the apple mildew fungus. The results with these new materials have not been outstanding. Apple mildew can be controlled, as was found out many years earlier, by the use of liquid lime-sulfur; but this material is open to serious objections and a new fungicide is definitely needed to solve this problem.

Not only was the production of organic fungicides accelerated by the war, but organic insecticides likewise were produced in everincreasing numbers after the introduction of DDT. These organic insecticides have been accepted by growers, but one of the important questions is whether or not these materials will have any residual effect in the soil since large quantities of insecticides sprayed on the trees eventually are deposited upon or mixed with the upper layers of the soil. Experiments on the effect of the accumulation of organic insecticides in the soil on the growth of peach trees and strawberry plants have been underway since 1945. The results obtained at the present time indicate that DDT remains as such in the soil for many years and that it has a very depressing effect upon root formation in the upper few inches of the soil.

The experiments on residual effects of other organic insecticides have not been in progress for a sufficient number of years to warrant any very definite statements. The recently introduced organic phosphate, Parathion, appears to volatilize rapidly and leave no objectionable residue in the soil.

Still another approach, current during the present decade, has been an attempt to improve the control of the apple scab fungus by the combined use of ground spray, originally developed by Keitt and his coworkers at the University of Wisconsin, followed by two applications of an organic mercury spray. This program has been used experimentally for four years by Department workers and the results have been very promising. One limitation to the procedure is the possibility

that ascospores from nontreated areas may be carried by the wind into treated orchards.

M. A. Smith studied the obscure bacterial disease of apples called blister spot at the Mountain Grove Experiment Station in Missouri. This had originally been reported to be due to a specific organism, but Smith's laboratory studies indicated it was merely a strain of Phytomonas syringae (= Pseudomonas syringae), a widely distributed greenish-white bacterial organism common on a variety of host plants.

The pathological work on small fruits likewise continued to expand. In 1940, Bergman, who had made preliminary investigations on the oxygen content of water in cranberry bogs, continued to investigate this phase of the problem and noted that ice and snow resulted in an oxygen deficiency for the plants in bogs flooded during the winter. This oxygen deficiency during the winter seriously affected the growth of the plants the following spring. At the same time Bergman and R. B. Wilcox tested ferbam and in 1945 they reported that this new organic fungicide was superior to bordeaux mixture for the control of cranberry fruit rots. They found that spray applied during the blossom period materially reduced the incidence of rot on the fruit at harvest time and during the storage period.

In 1942, Demaree and Marguerite S. Wilcox described a new blueberry canker due to Physalospora corticis and reported that spraying with either bordeaux mixture or liquid lime-sulfur gave inadequate control of this disease. In the same year R. B. Wilcox described a new virus disease of blueberries in New Jersey named "stunt" and four years later Demaree reported that "stunt" occurred in blueberry plants in North Carolina, Massachusetts, and Michigan as well as New Jersey. He found that the disease was spreading rapidly in North Carolina and New Jersey but only slowly in the other two Sttaes. In 1947, Demaree and Marguerite S. Wilcox published an account of the species of fungi, several of which were previously unknown, attacking blueberries, especially those grown in the South Atlantic and Gulf States.

In the strawberry project Bain and Demaree described in 1945 the red stele root rot caused by Phytophthora fragariae, which they found to be widely distributed in the United States. The same disease occurs in England and Scotland where it is called the "Lanarkshire" disease; English workers had described and named the causal fungus. Demaree also described, the same year, a bud rot of strawberry plants due to a species of Rhizoctonia which he found in Maryland and in the southern strawberry-producing sections. The fungus kills the flower and leaf buds during the first few weeks after new growth is resumed.

In 1948, Demaree announced that strawberry yellows, or xanthosis, had been discovered in the eastern strawberry sections. This virus disease had originally been described on western varieties of strawberries not suitable for growing east of the Rocky Mountains, and the eastern varieties do not show the conspicuous yellow-edge leaf symptom so characteristic of the disease in the West. As a control measure, Demaree suggested that all desirable varieties of plants be indexed and virus-free stock be propagated in a vector-free area. He recognized that the maintenance of a virus-free stock will require constant effort.

In 1943, Demaree and Marguerite S. Wilcox described a fungus producing a leaf spot of raspberries. They found similar fungi affecting blackberry and dewberry plants but the fungus from each host was morphologically and physiologically distinct.

In 1946, J. S. Cooley summarized his studies on root diseases of fruit trees. During the 12 years he studied this obscure problem he encountered Phytophthora cactorum, Sclerotium rolfsii, and Corticium galactinum, as well as other commonly recognized root-destroying fungi.

This account of the disease investigations would not be complete without mentioning the project on virus diseases of stone fruit directed by L. C. Cochran in Riverside, California, assisted by E. L. Reeves, H. C. Kirkpatrick, G. E. KenKnight, and B. N. Wadley. This group, working in close cooperation with State workers, have discovered or assisted in the identification of a large number of new virus diseases on stone fruits. Mottle leaf of cherry, Western-X disease, and little cherry have been among their main problems. So extensive have been their activities and so complex is the subject of cross inoculations, virus interrelations, and virus strains, that only a separate report could do justice to their investigations.

DIVISION OF FRUIT AND VEGETABLE CROPS AND DISEASES, BUREAU OF PLANT INDUSTRY, SOILS, AND AGRICULTURAL ENGINEERING, BELTSVILLE, MARYLAND

UNITED STATES DEPARTMENT OF AGRICULTURE RESEARCH ON DISEASES OF CITRUS AND OTHER SUBTROPICAL FRUITS, 1886-1950

Harry R. Fulton

As early as 1886 F. Lamson-Scribner described citrus scab from Florida material, called the disease orange-leaf scab, attributed it to a particular fungus, which he designated as Cladosporium sp., and suggested spraying with fungicides for its control. One of the fungicides suggested was "liquid grison", to be prepared by prolonged boiling of sulfur and lime, with subsequent dilution of the clear liquid, essentially a polysulfide preparation equivalent to lime sulfur solution, which later has been largely used for citrus scab control. He does not give results of actual use of this material. In 1891 L. M. Underwood, as special agent, was sent to Florida to make a preliminary study of citrus diseases for the Division of Vegetable Physiology and Pathology. His notes include accounts of die-back, foot rot, blight, scab, leaf spot (Colletotrichum), sooty mold, and leaf glaze (Strigula). Later in the same year Erwin F. Smith and W. T. Swingle went to carry on further studies, especially on blight. Swingle returned the following spring to continue the work. A field laboratory was established at Eustis, Florida, and H. J. Webber became associated with Swingle in the fall. This was probably the first scientific laboratory to be established for the express purpose of studying citrus diseases. The results of three years of intensive field and laboratory study by these investigators were presented in a bulletin entitled "The Principal Diseases of Citrous Fruits in Florida". The work is notable for the thoroughness with which it was done, and for the emphasis on experimental testing of control measures, many of which are still in successful use. Melanose was added to the list of major citrus diseases, and control was obtained with copper fungicides properly timed. In a somewhat later bulletin Webber summarized investigations on sooty mold and its treatment through spraying to control honeydew-excreting insects, especially the white fly. He pointed out for the first time the entomogenous nature of several species of Aschersonia. The destructive freezes of 1894 and 1895 led to suspension of the disease investigations by Swingle and Webber at Eustis.

From 1901 to 1906 P. H. Rolfs at the Bureau of Plant Industry Field Laboratory at Miami investigated anthracnose of lime and other citrus fruits as well as of mango and avocado. He was succeeded by Ernst A. Bessey, whose work for two years included investigations of citrus blight, anthracnose of various subtropical fruits, and nematode host range and distribution.

In 1912 J. G. Grossenbacher began studies on citrus diseases in the Division of Fruit Disease Investigations, with Florida headquarters at Plymouth. His work was broadly planned to obtain information about some of the more baffling bark and wood diseases.

The appearance of citrus canker and the determination of its pathogen (Pseudomonas (Xanthomonas) citri) by Clara H. Hasse ushered in an expanded program for all citrus disease investigations, and H. R. Fulton was placed in charge (until 1935). The field laboratory was moved to Orlando and a special isolated greenhouse for canker studies was built on the Dairy Husbandry Farm at Beltsville, Maryland. The work on established diseases in Florida was under the successive leadership of J. R. Winston, F. A. Wolf, and H. E. Stevens, with the assistance at various times of J. J. Bowman, W. J. Bach, and J. F. Wootten. The research was aimed primarily at solving the growers' problems, and at obtaining a thorough knowledge of the behavior of the pathogens and of the reactions of the hosts. Nutritional disorders were also investigated.

Swingle and Webber had proved that scab and melanose could be controlled with Bordeaux mixture, but its use was followed by increase in scale insects, commonly presumed to be because of reduction of entomogenous fungi, and growers were certainly justified in a reluctance to use it. The Orlando staff found lime-sulfur solution to be satisfactory for light and moderate infections of scab, but it was not sufficiently effective under severe conditions, and it did not give satisfactory control of melanose. More effective control of scab was obtained with a "clean-up" application of bordeaux mixture to cover hold-over lesions on the old leaves, before the spring flush of new growth, and the addition of wettable sulfur to diluted lime-sulfur solution for the fruit cover applications gave a highly effective spray program with a lessened risk of insect trouble.

Melanose was easily controlled with a single cover application of bordeaux mixture under ordinary conditions, but other fungicides were not sufficiently effective. The problem here was to modify the bordeaux mixture so as to get away from the consequent scale insect increase. This was partially effected by reducing the strength of the spray, and by adding oil emulsion. A great variety of other copper fungicides were tested, and for a number of years none was found equal to bordeaux mixture in effectiveness against melanose. A rapid method was developed for testing the residue of copper in spray coatings on leaves. Some of the fixed copper materials that left less residue on the leaves proved to be less likely to incude scale increase. At the present time tribasic copper sulfate is the preferred material for melanose control.

Plantings of Mexican type limes on the Keys were suffering from outbreaks of lime wither tip (Gloeosporium limetticolum). Extensive trials failed to give economical control through spraying, because of the irregularity of blooming and consequent frequency of applications necessary to protect the developing fruit. It was shown that the disease could be greatly reduced by a clean-up application of bordeaux mixture before the new flush appeared, followed by lime-sulfur solution in the bloom and at intervals of a week until the fruits were 3/8 inch in diameter. Pruning, timing of fertilizer applications, and watering practices to induce more regular blooming and fruit setting would be necessary for successful control by spraying; however, these were not practicable under the conditions for growing limes on the Keys.

For all three diseases, scab, melanose, and lime wither tip, the range of host susceptibility, influence of age of tissue, and environmental conditions affecting persistence, spread, and infection were closely studied and the information was used in devising control measures.

Two types of tear-stain surface blemish of citrus fruits occur in Florida and are readily distinguishable, one rough, the other smooth. The rough type is a pattern of melanose injury in the path of trickling water laden with enormous numbers of Phomopsis citri spores. The smooth type of tear-stain was commonly attributed to similar distribution of spores of the omnipresent anthracnose fungus Colletotrichum gloeosporioides. Early in his scab spraying experiments Winston noted that smooth tear-stain was abundant on plots receiving bordeaux mixture, but was absent from those sprayed with lime-sulfur, whereas both fungicides should have been effective against Colletotrichum spores. Furthermore, the well known diffuse type of rust mite injury was present in all plots showing smooth tear-stain but not in the others. The timing of the lime-sulfur applications was right for rust mite control. Additional evidence was obtained from histological comparisons, culturing attempts, and inoculation tests, as well as from extensive field studies of possible association with rust mites or with Colletotrichum and of the effects of spraying practices, all of which led to the conclusion that the smooth, so-called wither tip type of tear-stain in Florida is in reality caused by rust mites and can readily be prevented by controlling the mites.

In cooperation with the Orlando staff, Anna E. Jenkins (1925) worked out the identity of the scab fungus (Sphaceloma fawcetti). A few years later she was sent to Brazil to study a form of scab that had been intercepted on sweet orange fruits, which are practically immune from the common scab of Florida. In 1933 she described this South American sweet orange fruit scab pathogen as Sphaceloma fawcetti var. viscosa. Still later (1936), the perfect stage was found in Brazil, and was described as Elsinoë fawcetti by A. A. Bitancourt and Anna E. Jenkins. During this period Wolf (1926) discovered the perfect stage (Diaporthe citri) of the melanose-producing Phomopsis citri; and N. E. Stevens (1926) found the perfect stage of Diplodia natalensis, the cause of one form of stem end rot, to be Physalospora rhodina. Wolf studied Corticium thread-blight on citrus and other hosts; Winston had previously obtained control of this disease on citrus with one application of bordeaux mixture just before the onset of the summer rainy season.

The discovery of citrus canker in Florida and other Gulf States (1914) brought a crisis to the citrus industry, which was successfully met by a drastic eradication campaign carried on cooperatively with the States involved. K. F. Kellerman, as member of the Federal Horticultural Board and associate chief of the Bureau of Plant Industry had much to do administratively with the success of the undertaking, which is one of the most remarkable achievements in the history of plant-disease control. At the outset, conflict in ideas about the nature of the disease was removed by Clara H. Hasse's determination of its bacterial nature. Her work continued on the physiology of the organism, the relative susceptibility of citrus and other rutaceous hosts, and the effectiveness of bactericides. At the same time Fulton investigated the persistence of the canker organism in the soil and the infectibility of citrus fruits. All of the greenhouse investigations were in close cooperation with the eradication and quarantine work, and were intended to supply needed information.

Since the eradication program made it impossible to carry on control experiments in the citrus-producing regions of the United States, H. Atherton Lee was sent (1916) to the Philippine Islands and to Japan to study field behavior of the disease and methods of control. This seemed important in case eradication proved not to be successful. His work resulted in a series of papers dealing with various phases of the canker problem, as well as with other citrus diseases in the Orient.

An early study of citrus fruit decay was by N. B. Pierce on the Alternaria rot of California navel oranges, in 1901. G. H. Powell's comprehensive study of transportation decay in oranges from California, published in 1908, centered attention on careful handling to avoid invasion by the Penicillium rots. Similar studies with Florida oranges were published in 1914 by A. V. Stubenrauch, H. J. Ramsey, and L. S. Tenny.

Two very serious stem-end rots are prevalent in the Gulf Coast region, caused by Phomopsis citri and Diplodia natalensis. Both become incipiently established in the fruit during its develop-

ment but decay does not develop until after the fruit is harvested. Early in the work at the Orlando Laboratory it was realized that means must be found for preventing the incipient grove infection or for delaying the development of rot after harvest. The problem was accentuated by the "degreening" treatment in coloring rooms under conditions that promoted development of stem-end rot, especially the Diplodia form. It was early found that the spray treatments for melanose control also reduced the subsequent development of Phomopsis stem-end rot, but only slightly reduced Diplodia rot. Both fungi are harbored in dead limbs and twigs. Pruning out such sources of infection was more effective against Diplodia than against Phomopsis, seemingly because the latter fungus was abundantly present in dead fruit stalks and very small twigs that could not be thoroughly pruned out. Diplodia rot develops most rapidly at temperatures some ten degrees above the optimum for Phomopsis. This explains in part why this form of rot was often more conspicuous in the warmer periods of the shipping season, in the warmer producing districts, and following the degreening treatment in the warm coloring rooms. Both forms of rot are satisfactorily retarded by moderately low temperatures, less cooling being required for Diplodia than for Phomopsis. The stem "buttons" seem to be the part first invaded by the stem-end rot fungi, and it was found that removal of these buttons in the process of degreening effectively prevented stem-end decay. Dipping the harvested fruit in borax solution, first found effective against Penicillium rots, proved to have considerable retarding effect on both forms of stem-end rot, and various forms of borax treatment have been widely used to prevent loss from all of these types of decay.

Notable early studies of tropical fruit diseases were on the bud rot of coconut palms by J. R. Johnston and on the Panama disease or Fusarium wilt of banana by Erwin F. Smith, who described and named the causal fungus.

A disease of Florida pineapples, known as "red wilt", was found by Winston to be a complex in which soil depletion and nematode attack played a part. Control was obtained by rotation with soil-improving cover crops that were resistant to the root knot nematode.

Spraying for control of mango anthracnose, especially the bloom blight phase which prevents fruit setting, was carried on by S. M. McMurran, and later by H. E. Stevens, with reference also to protecting the fruit from blemish and decay. Stevens and R. B. Piper developed successful spraying programs for protection of avocado fruit and foliage from scab, Cercospora leaf spot, and anthracnose. Stevens also investigated sun blotch, a virus disease of avocado, as well as psorosis of citrus, also a virus, and various papaya diseases.

On the retirement of H. E. Stevens in 1945, J. F. L. Childs became leader in the disease work at the Orlando field laboratory. His discovery, in collaboration with E. A. Siegler, that thiourea and certain other fungistats could penetrate citrus fruit tissues and thus control stem-end decay led to expanded efforts along this line. Following this work screening tests with some 1500 compounds have been made at the Orlando laboratory by the fruit-handling staff. Childs' tests of 8 organic fungicides for control of melanose of citrus showed that none of them gave promise of replacing the copper sprays already in use. Work is in progress on testing a large number of citrus rootstock varieties for resistance to foot-rot Phytophthora; on a new disease, presumably virus, on Orlando (Lake) tangelo, to which the name cachexia is given; on the nature of citrus gummosis diseases in Florida; and on the cause of an obscure type of tree decline in that State.

The uneasiness caused by the rapid spread and destructiveness of the tristeza disease of citrus in South America led to the sending in 1946 of C. W. Bennett to Brazil to conduct investigations in cooperation with the Instituto Agronomico do Estados de São Paulo, at Campinas. His work in cooperation with A. S. Costa confirmed the finding of others that the tristeza disease is caused by a virus, transmissible by budding, and that it is spread naturally by the black citrus aphid, Aphis citricidus. Varietal susceptibllity was studied, and the effectiveness of various control measures, none of which seemed satisfactory for general use. Sweet orange, rough lemon, Rangpur lime, and sweet lime as rootstocks seemed to give stock-scion combinations satisfactorily resistant to injury.

Bennett was succeeded in 1947 by Theodore J. Grant. The reactions are being studied of a large number of citrus varieties as rootstocks for sweet orange and grapefruit, and as scions over sour orange and other rootstocks, when inoculated with tristeza virus. Altogether 345 stock-scion combinations are under test, the most promising ones being transplanted in orchard formation for further observation. Tristeza -tolerant rootstocks include various types of sweet orange and mandarin; some lemon and tangelo varieties; and certain other hybrids are promising. None of the 15 varieties of sour orange have proved to be satisfactory. A difference in severity of tristeza was found to be transmissible and is regarded as being due to distinct strains of the virus.

As a precaution against possible outbreak of tristeza in this country, extensive tests are being made of the disease resistance, hardiness, and general suitability of a wide range of citrus types and varieties for use as rootstocks in Florida and in Texas (cooperative work led by W. C. Cooper), especially for use in districts where susceptible sour orange is now in general use in commercial plantings.

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DIVISION OF FRUIT AND VEGETABLE CROPS AND DISEASES, BUREAU OF PLANT INDUSTRY, SOILS, AND AGRICULTURAL ENGINEERING

INVESTIGATIONS OF NUT DISEASES

John R. Cole and Paul W. Miller

PECAN DISEASES

In the early stages of pecan orcharding scab (Cladosporium effusum) was present in destructive amounts on only a few of the improved varieties. Pioneer work on control by spraying was conducted by M. B. Waite at Orangeburg, South Carolina, in 1909, and at Baconton, Georgia, in 1911. The spray equipment of that period was inadequate for use on large pecan trees, and many growers preferred to shift to the more resistant pecan varieties. From 1912 to 1918 thousands of trees of the most susceptible varieties in the humid Gulf Coast area were top-worked to the more resistant varieties. This relief was shortlived, for the scab fungus gradually became destructive on the previously resistant varieties. Furthermore, new introductions regarded as resistant began to show partial to total crop losses from scab soon after they had become extensively planted. The one outstanding exception is the Stuart variety, on which scab does not seem to be increasing in severity. Orchard observations by J. B. Demaree and J. R. Cole suggested the existence of physiologically specialized strains of the pathogen. Experiments showed that when conidia from various sources were applied to several varieties known to be susceptible the heaviest infection resulted when the inoculation was made on the same variety as that from which the conidia were taken.

Since 1918 extensive spraying experiments for scab control have been carried on, in which a wide range of fungicides and improved means of application have been thoroughly tested; and recommendations have been made for economical control by a combination of cultivation to bury hold-over husks and leaves, pruning to give more open tops, and proper timing of 4 or possibly 5 spray applications to protect leaves and nuts during their period of susceptibility, which extends well through the summer in the case of the nuts. Spraying equipment must be capable of effective work on trees 40 to 60 feet in height, or even taller. Home-made bordeaux mixture with low lime content still holds its place at the top in effectiveness. Recently ziram is giving good scab control, with more healthy, greener foliage and less severe black aphid infestation than have followed use of bordeaux mixture. However, ziram is "specific" in the case of certain varieties, e.g., Moore and Schley, but is less effective on others, such as Moneymaker.

Pecan scab control investigations are being continued, including the new types of fungicides and methods of application, especially mist sprayers applying concentrated materials, which may prove to be especially advantageous in pecan orchards.

Several fungi attack pecan leaves, causing functional decline and premature defoliation, with consequent reduction in nut quality and yield. These fungi do not destroy the nuts, and they are readily controlled by orchard sanitation and spraying. Studies on the morphology, physiology, pathogenicity, and control of leaf blotch (Mycosphaerella dendroides) and downy spot (Mycosphaerella caryigena) have been reported by Demaree and Cole, and of vein spot (Leptothyrium nervisedum) and liver spot (Gnomonia caryae var. pecanae) by Cole, all published in the Journal of Agricultural Research, 1930-33.

A disease of pecans, known as "bunch", is characterized by a witches'-broom type of growth. It is found west of the Mississippi River on the native pecan and water hickory, and in many planted orchards. The Schley and Mahan varieties are the most susceptible, while the Stuart is the most resistant. Bunch is infectious, but no parasite has been identified, therefore it is probably a virus disease.

Pecan rosette was investigated by W. A. Orton and F. V. Rand, who reported in 1914 that no parasitic organism was associated with the disease and concluded that the cause of the trouble was in the soil; it was thought that "the direct cause will ultimately be found in some lack of balance in the nutrient supply." S. M. McMurran worked on the problem from 1914 to 1920. He found that rosette was usually associated with soil unsuitable for thrifty growth, either of pecan trees or of weeds and crops generally. He indicated deficiency of humus, of plant-food material, or of moisture, or a combination of these, as being factors. In 1919 Waite reported: "Extensive field experiments on pecan rosette have shown this disease to be physiological and due to soil conditions. Stable manure has been demonstrated to be an effective, though not always practical, remedy for these conditions."

J. J. Skinner and Demaree (10), in their experimental work with rosette in southern Georgia, were able to bring badly rosetted trees that were growing on soils low in organic matter back to normal by growing and turning under two green manure crops each year. Chemical fertilizers, as used in the experiment, had no influence in increasing or decreasing rosette.

In 1931 A. O. Alben, J. R. Cole, and R. D. Lewis (1), while conducting experiments to control rosette, concluded that "pecan rosette is apparently a nonparasitic disease of widespread distribution occurring on both residual and alluvial soils. The writers were able to improve old rosetted leaves and bring the young ones back to normal by dipping or spraying them with a solution of ferric sulfate or ferric chloride, ranging in strength from 0.6 to 1 percent. These findings would seem to indicate that pecan rosette is a condition of iron chlorosis."

In 1932 these investigators further discovered that "with the enlargement of these experiments undertaken at the beginning of the 1932 season, more or less conflicting results began to appear. The experiments included injection of iron salts into dormant trees; application of iron salts to the soil around the trees, while they were still dormant; after the foliage was well developed, spraying by various procedures with both ferric and ferrous sulfate; and dipping terminal branches that showed the rosette symptoms in solutions of iron salts. The only favorable results were associated with the small-scale experiments where galvanized iron containers were used in handling the solutions. It was further found that the iron salts used contained appreciable quantities of zinc. Accordingly, a small series of experiments were undertaken, using shellaced crocks instead of galvanized buckets. The effects of zinc sulfate and zinc chloride solutions were compared with the effect resulting from iron sulfate solution. One immersion in the iron solution failed visibly to improve conditions, while zinc sulfate and zinc chloride solutions restored the new leaves back to normal condition. These results were secured with trees located on both alkaline and acid soils.

"Our experiments in spraying foliage with zinc sulfate or zinc-lime sprays and also the experiments in dipping terminal parts of branches showing pronounced rosette symptoms in zinc solutions and the prompt and favorable response of the trees to such treatments apparently indicate that zinc is an essential element for the healthy development of the pecan tree."

The investigations of Alben, Cole, and Lewis in the western part of the pecan belt, where soils are mostly alkaline, were supplemented by extensive experiments conducted by J. B. Demaree, H. L. Crane, and E. D. Fowler on acid soils of the Southeast. In this way the problem of zinc deficiency control was quickly solved and growers were enabled to overcome the disease throughout the area of commercial production. Control is readily obtained by spraying with a solution of zinc sulfate or by broadcasting the chemical; but the latter method is effective only under acid soil conditions. The solving of this important problem has materially aided growers in their pecan production program.

WALNUT DISEASES

An early reference to walnut bacteriosis, or blight, occurs in the 1893 report of the Chief of the Division of Vegetable Pathology of the U. S. Department of Agriculture. In 1896 and during the next five years N. B. Pierce published accounts of it as found on Persian walnut in California, with discussion of the life history of the causal organism and reports on limited attempts to control the disease. In 1901 he published a technical description of the causal bacterium, giving it the name Pseudomonas juglandis. In the Eastern States the disease was later studied by S. M. McMurran, who published his findings in 1911. B. A. Rudolph of the California Agricultural Experiment Station, in 1928, obtained successful control by spraying in the growing season, rather than in the winter dormant period.

In 1930, Paul W. Miller began work on the problem under Pacific Northwest conditions in cooperation with the Oregon Experiment Station. Attempts to control by Rudolph's program gave variable results under conditions there. Miller made a complete study of the epidemiology of the disease and applied the information to the problem of effective control. Several satisfactory spray and dust formulas were worked out, and the proper timing of applications determined. In collaboration with W. B. Bollen of the Oregon station, a comprehensive technical bulletin was prepared covering the physiology of the causal organism, its life history in relation to pathogenesis, and the development of control measures.

Investigations are in progress to test efficiency of new organic materials, and of concentrated sprays applied with modern high-power mist sprayers. Several other important walnut disorders in Oregon have been studied including non-parasitic "black line", a leaf scorch and twig dieback due to deficiency of boron, crown rot, mushroom root rot, and an undetermined rot of crown and roots.

FILBERT DISEASES

In the cooperative nut disease investigations in Oregon primary consideration is being given to filbert bacteriosis, caused by Xanthomonas corylina. Other diseases of importance have received attention; including powdery mildew, crown gall, mushroom root rot, and wood and heart rots caused by a variety of wood-rotting fungi.

The main infection period for filbert bacteriosis was found to extend from the time the winter buds are about three-fourths grown (late summer) until they open the following spring. Cankers on trunks and larger branches are the most important source of primary inoculum. Methods for control were worked out for prevention of extensive establishment of the disease in young trees and for spraying older trees with a protectant bactericide. In normal seasons one spray application made in late summer before the first fall rains gives satisfactory control. A complete report on filbert bacteriosis was published as an Oregon technical bulletin by P. W. Miller, W. B. Bollen, and J. E. Simmons.

Miller and C. E. Schuster investigated the effects of high-lime and low-lime bordeaux mixture on the transpiration rate of Persian walnut and filbert plants. No uniform effects were noted on either walnut or filbert, and there was no marked difference between the two types of bordeaux mixture.

TUNG DISEASES

Thus far tung orchards in the Southeastern States have been remarkably free from destructive outbreaks of infectious diseases. This is especially fortunate since the returns from the crops do not justify expensive control procedures. The tung tree has been rather quick to show effects of nutrient deficiencies in certain types of soil in the tung belt, but these disorders can be readily and economically remedied once they are recognized. The parasitic diseases that have shown up are mostly sporadic and are caused by well-known organisms that are somewhat weakly parasitic on a considerable range of host plants in the tung belt.

J. R. Large investigated a girdling canker disease found in a nursery and on young orchard trees in several localities. He attributed the disease to Physalospora rhodina. The perfect stage, as well as the Diplodia form, was found associated with the cankers.

Thread blight (Corticium stevensii) and web blight (Corticium microsclerotia) have been occasionally encountered. Experiments have shown that control of thread blight by pruning is not practical after the disease has become established in a bearing tung orchard, but that spraying with bordeaux mixture once a year early in June will control it. A nut rot attributed to Botryosphaeria ribis causes premature dropping of fruit and reduction in oil content. A few instances of death of trees from Clitocybe root rot have been observed. Root knot nematodes have caused stunting of tung trees in the nursery.

Lucia McCulloch and J. B. Demaree isolated a bacterium from tung leaf spots and infected healthy plants by inoculating with the pure cultures. They named the organism Bacterium aleuritidis.

Demaree and Large studied a type of tung leaf variegation which seemed to involve an inheritance factor rather than the presence of virus.

Large investigated a disease that caused rough bark and willowy twisted branches of tung; he transmitted it by budding, which indicates, in the absence of any causal organism, that the disorder is a virus infection.

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DIVISION OF FRUIT AND VEGETABLE CROPS AND DISEASES, BUREAU OF PLANT INDUSTRY, SOILS, AND AGRICULTURAL ENGINEERING

DISEASE INVESTIGATIONS WITH ORNAMENTAL CROPS IN THE UNITED STATES DEPARTMENT OF AGRICULTURE

Philip Brierley

INTRODUCTION

Ornamental plants have always had a strong appeal to plant pathologists, as is shown by the research issuing from divisions operating under broad directives. Even before the Department of Agriculture attained cabinet rank in 1889, studies on diseases of ornamentals were included in the Commissioner's Reports. Later a great many contributions of value came from Erwin F. Smith's Laboratory of Plant Pathology. Also, from the Division of Mycology we have a number of substantial papers. The work of the Division of Nematology and of the Division of Forest Pathology is not included here, although these divisions also deal with ornamental plants in part. It was not until 1926 that the Department had a specific directive to study diseases of ornamental plants and a project was organized for this purpose with the Division of Cotton, Truck, and Forage-Crop Disease Investigations. This work is now a part of the Division of Fruit and Vegetable Crops and Diseases. The alarm felt by producers of narcissus over losses incurred from basal rot was largely responsible for the initiation of these studies. At length research did produce a commercial control for this disease, as is pointed out in a later paragraph. In order to keep this discussion within bounds, the many research publications by Department workers on diseases of ornamentals are briefly sketched, followed by one selected accomplishment -- the control of narcissus basal rot --, and a sample current research project -- the control of diseases of gladiolus.

At the outset work on diseases of ornamental plants was quartered in the West Wing of the Department of Agriculture building, with greenhouse space at 12th and Constitution Avenues and later at Arlington Farm. In 1935 this work was moved to Beltsville to the new Horticultural Field Station, now Plant Industry Station, to become a part of a new project on Florists' and Nursery Crops. The disease work was originally staffed by Freeman Weiss and the writer. Lucia McCulloch joined us after E. F. Smith's group was disbanded in 1930; she retired in 1941. In 1941 W. D. McClellan came to Beltsville and in 1942 D. L. Gill began studies on azalea diseases at Baton Rouge, Louisiana, continued later at Spring Hill, Alabama. Other workers served more briefly, Thelma Bennett Post and E. L. Evinger at Beltsville and J. F. L. Childs and Cynthia Westcott at Spring Hill. Cooperative relations have long been maintained with the Oregon Experiment Station at Corvallis, with M. B. McKay and, later, F. P. McWhorter as agents of this Division. Similar cooperation with the New York (Cornell) Experiment Station at Babylon and Farmingdale, Long Island, has been staffed at various times by F. A. Haasis, D. B. Creager, C. E. Williamson, and A. A. Foster as agents or collaborators. Our group has enjoyed excellent cooperation from the Division of Truck Crops and Garden Insects of the Bureau of Entomology and Plant Quarantine. F. S. Blanton of that division worked on vector relations of narcissus viruses with F. A. Haasis, and Floyd F. Smith has made vector studies of a wide range of viruses of ornamental plants in cooperation with the writer. N. W. Stuart, physiologist of our own project, has made a number of contributions on nutritional relations of pathogenic fungi and on deficiency diseases of ornamental crops.

SOME EARLY BEGINNINGS: In the Reports of the Commissioner of Agriculture and, after 1889, of the Secretary of Agriculture are to be found a number of papers on plant diseases, including a few on the diseases of ornamental plants. One of the earliest of these was Thomas Taylor's account in the Commissioner's Report for 1871 of mildew of the lilac "genus *Microsphaeria*", including sketches of the conidial and perithecial stages that are recognizable but unskilled. The quality of these papers improved steadily, but for the most part they continued to be informative reports rather than original studies. In 1887 F. L. Scribner included descriptions of rose blackspot and two rust diseases of rose in his extensive report for the Section of Vegetable Pathology. In 1889 D. G. Fairchild presented a description of the disease of mignonette caused by *Cercospora resedae*. Miss E. A. Southworth, the first lady scientist in this field in Government service, in 1888 distinguished the rose leaf spot caused by *Cercospora rosaecola* from the better known blackspot. In 1890 she revised the description of hollyhock anthracnose and its causal agent *Colletotrichum malvarum*. In 1897 A. F. Woods presented an account of the Bermuda lily disease. His description strongly suggests the virus disease now known as necrotic fleck, but other defects were doubtless confused with this, and a virus cause was not visualized. P. H. Dorsett, in his Spot Disease of the Violet (1900) described an important disease of a crop then extensively cultivated. He erected a new species *Alternaria violae* for the causal agent and proved its pathogenicity.

E. F. SMITH AND THE LABORATORY OF PLANT PATHOLOGY: Erwin F. Smith entered the Department in 1886 to undertake a study of peach yellows. He failed to solve this problem, but attained world prominence in plant bacteriology, and gathered in his Laboratory of Plant Pathology a staff of skilled workers in this special field. Smith's own studies ranged over all classes of crops including a few ornamentals. He described (1896) Bacillus (Pseudomonas) solanacearum, and with his colleague C. O. Townsend (1907) named the crown gall organism Bacterium (Agrobacterium) tumefaciens -- two pathogens of wide host range and of significance to ornamental plants. He assigned the name Bacterium (Pseudomonas) woodsii to the carnation leaf-spot pathogen earlier noted by A. F. Woods, and rechecked in detail the earlier work of Wakker in Holland on hyacinth yellows caused by Pseudomonas (Xanthomonas) hyacinthi. Townsend in 1904 described Bacillus (Erwinia) aroideae, one of the soft rot bacteria attacking calla lillies and other plants. Three of Smith's staff of specialists in bacterial diseases joined the Division of Fruit and Vegetable Crops and Diseases after the Laboratory of Plant Pathology was disbanded following his death in 1927. Nellie A. Brown, Mark K. Bryan, and Lucia McCulloch each contributed significant work on diseases of ornamentals both before and after that change. Miss Brown described Bacterium (Pseudomonas) aptatum causing a leaf spot of nasturtium and beet, and Bacterium (Xanthomonas) pelargonii causing a troublesome leaf spot of the florist's geranium (Pelargonium spp.). She also distinguished Bacterium (Agrobacterium) gypsophilae, as the cause of a root gall of Gypsophila, and Phomopsis sp. as the causal agent of a stem gall of Viburnum spp. Both of these gall diseases had been confused with crown gall, with which Miss Brown had worked extensively. Mary K. Bryan described Bacterium (Xanthomonas) cannae causing budrot of canna, and, with F. P. McWhorter, Bacterium (Xanthomonas) papavericola, the cause of blight in poppies. She also made detailed studies of the pathogens of bacterial leaf spot of Delphinium, and of lilac blight, both of which had been described earlier. Lucia McCulloch described the pathogens of gladiolus bacterial blight, Bacterium (Xanthomonas) gummisudans, and of gladiolus scab, Bacterium (Pseudomonas) marginatum, and also the agent of leaf blight of iris, Bacterium tardicrescens, and that of a leaf spot of begonia, Bacterium (Xanthomonas) flavozonatum, the last not certainly distinct from the earlier X. begoniae. With R. P. White she made a detailed study of the bacterial leaf spot of English ivy and of its causal agent, Xanthomonas hederae. Later, with Charles Thom, she described Penicillium gladioli, the cause of a corm rot of gladiolus, and studied Fusarium corm rot of gladiolus and its control. Other contributions from the Laboratory of Plant Pathology on fungus diseases were F. V. Rand's description of Helicosporium (Helicoceras) nymphaearum and the leaf spot it induces in pond lilies, and Harry Braun's study of geranium stem rot caused by Pythium complectens. These papers from the Laboratory of Plant Pathology are scholarly, and have stood the test of time except for nomenclatural changes. They are mainly descriptive contributions. Suggestions for controlling the diseases are usually sanitary measures or are lacking. Indeed, the bacterial diseases are still difficult to control, and perhaps the lack of effective and immediately useful remedies may account for the decline of plant bacteriology from its former position of eminence to near the vanishing point in this Department.

CONTRIBUTIONS FROM THE MYCOLOGISTS: Continuing the work begun by Scribner and Southworth members of the Division of Mycology and other mycological workers have clarified several of the fungus diseases of ornamentals. In 1910 Flora W. Patterson and Vera K. Charles noted Botrytis paeoniae causing peony blight, and B. cinerea causing ray blight in florists' chrysanthemums. An anthracnose of cyclamen was shown to be caused by a variant of Glomerella rufomaculans, which they described as a new variety. Anna E. Jenkins described brown canker of rose, a troublesome disease in eastern and southern United States, since found also in Europe, that had been confused with other canker diseases and with winter injury. The pathogen which she described as Diaporthe umbrina is now referred to as Cryptosporella, for the ascospores are usually unicellular. Miss Jenkins presented the original descriptions of the disease and of the pathogen, and also studied its seasonal development in detail. She also described Sphaceloma rosarum, cause of the nearly worldwide spot anthracnose of roses, which had been misinterpreted and confused with other leaf spot diseases. With N. E. Stevens she showed that the currant cane blight fungus Botryosphaeria ribis can cause die-back in roses. With L. M. Massey she described another spot anthracnose, or scab disease, of violets caused by Sphaceloma violae. Miss Jenkins also established Ascochyta majalis, a fungus previously known only from Europe, as the cause of a leaf spot of lily-of-the-valley. Alma M. Waterman of the Division of Forest Pathology, who was long assigned to the study of rose diseases, presented a comparative study of the Coniothyrium cankers of rose -- brand canker caused by C. wernsdorffiae and cane canker by C. fuckelii.

RESEARCH IN THE ORNAMENTALS PROJECT

BULB DISEASES: Narcissus. Two leading diseases of narcissus are omitted here: Fusarium basal rot is reserved for special treatment below, and the narcissus nematode disease is omitted as being outside the scope of this review. A general account of diseases affecting narcissus offered by McWhorter and Weiss in 1932 includes these diseases and others known at the time. Narcissus bulbs are subject to wet scale rot caused by Sclerotium rolfsii and to two scale speck organisms assigned to Sclerotium spp., as well as to Rhizopus rot after injury. Leaf diseases are smoulder caused by Botrytis narcissicola, leaf scorch due to Stagonospora curtisii, and white mold, Ramularia vallisumbrosae. Creager studied the morphology and life cycle of Stagonospora in detail. Two virus diseases are generally prevalent, reducing bulb yields and impairing flower quality. Mosaic, called yellow stripe in Europe, was first shown to be sap transmissible at the Oregon Station; but Haasis at Babylon, New York, first determined properties of the virus and later F. S. Blanton and Haasis showed that seven species of aphids can serve as vectors. A second virus, causing the disease known as white streak or decline disease, has been shown by Haasis to be sap transmissible and by Blanton to be aphid borne. The cooler climate of the Pacific Northwest is less favorable for development of Fusarium basal rot and also for increase of the aphid vectors of the virus diseases, but is favorable for bulb increase. For these reasons narcissus production is intensified in that area, although leaf diseases of negligible importance in Eastern centers may require additional control measures in the Northwest.

Tulip. Department research on tulip diseases has been largely confined to the virus disease tulip mosaic, or tulip breaking. The striking rearrangement of color in the broken flower is so distinctive that the existence of tulip breaking can be traced far back into history, to 1576, as shown by M. B. McKay and M. F. Warner. Proof that breaking is due to a virus transmissible by sap and by aphids was presented independently by English workers and by McKay, Brierley, and T. P. Dykstra at about the same time. More recently extensive studies on tulip breaking have been reported by McWhorter, and by Brierley and Smith. McWhorter has offered a theory that the light and the dark breaking patterns in tulips are produced by two distinct viruses that are present in balanced proportions in the common broken tulip, which shows a mixture of light and dark areas. Tulips infected at flowering time develop breaking in the following season, but if plants are infected early they may express symptoms in the same season. Cucumber mosaic virus can affect tulip, but this disease is uncommon in tulips in the United States and readily distinguished from tulip break. Some lily mosaic strains can induce breaking in tulips as McWhorter first demonstrated. Control of tulip breaking is more practicable in areas of low aphid prevalence, and roguing to eliminate disease is complicated by weak expression of symptoms in white and yellow tulip varieties.

Lily. Virus diseases, which are of major importance in lily culture, have been studied intensively by Department workers. Close teamwork between Pathology and Entomology bore fruit in the studies of Brierley and Smith on necrotic fleck and on mottle of Easter lilies. The necrotic fleck disease, first introduced into Louisiana, has become generally distributed in the Southeast but is still rare in the Northwest where exclusion has been more rigidly practiced and where aphid vectors are less abundant. This disease of the Easter lily has been shown to be caused by a complex of two viruses. One is the common cucumber mosaic; the other is a virus peculiar to Easter lily and inducing no symptoms when present alone, which Brierley and Smith have designated lily-symptomless virus. This symptomless virus is carried by Aphis gossypii only, and in the persistent manner. It has become general in commercial stocks of Easter lily, presenting no warning of its presence until cucumber-mosaic virus is added. Cucumber-mosaic virus, present in flecked lilies and sporadically in vegetable crops, in certain other ornamentals and wild hosts, may be carried by Myzus persicae and Macrosiphum solanifolii, as well as by Aphis gossypii, in the non-persistent manner in each. Migrant aphids of any of these species, notably M. persicae, may spread the cucumber-mosaic virus at amazing rates as they pass over Easter lily fields, leaving necrotic fleck symptoms to develop later. If aphids are not controlled under glass, similar increase of fleck may take place before the crop is marketed. A third virus, which we have termed lily-mottle virus, is extremely common in commercial stocks of Easter lilies. This virus, a member of the tulip-breaking group, is not recognizably damaging to Easter lilies, but is ruinous to some garden lily species and to tulips. It is transmitted in the non-persistent manner by the three species of aphids mentioned above. None of the lily viruses are known to be seed borne.

Lily-rosette virus, transmitted by Aphis gossypii only, and in the persistent manner, has been shown to be capable of infecting a number of other Lilium species (Smith and Brierley). The rosette disease is difficult to diagnose for symptoms may be imitated by other disorders, such as the feeding injury of Myzus convolvuli. McWhorter and Brierley have developed a technique for diagnosing rosette from the phloem abnormalities induced. Smith and Brierley have shown that lily

viruses of both persistent and non-persistent classes may be transmitted during storage of the bulbs if the appropriate vector species is present in the storehouse. A mosaic disease common in Ornithogalum and certain other members of the tribe Scilleae of the Liliaceae is distinct from the lily viruses and not transmissible to lilies.

Fusarium rot of lily bulbs, caused by F. oxysporum f. lilii, is limiting in production of some lily species, and particularly destructive of the bulb scales when these are used in propagation. McClellan and Stuart have tested a number of fungicides, alone and in mixture with hormones, as protectants against this decay of lily scales. Formaldehyde proved injurious to the scales, but Arasan and Fermate provided good protection against rot of the scales both under glass and in the field. No significant advantage was found in the use of these same fungicides on bulb planting stock. Charles Drechsler has identified Phytophthora cactorum as the cause of a foot rot in certain garden lily species. A leaf scorch peculiar to the Croft variety of Easter lily has been shown by N. W. Stuart to be a nutritional disorder that may be corrected in part by side dressings of nitrogen fertilizer.

Iris. Diseases of bulbous iris and their control were discussed by McWhorter (1940). Bulb rots caused by Sclerotium rolfsii and by Penicillium sp. have been studied by Weiss, and the leaf diseases caused by Mystrosporium adustum and Heterosporium iridis (Didymellina macrospora) by McWhorter. Miss McCulloch's work on bacterial leaf spot of iris has been noted above. The mosaic of bulbous iris was originally described by Brierley and McWhorter. This virus is sap transmissible and carried by Myzus persicae and by Macrosiphum solanifolii. More recently Brierley and F. F. Smith have shown that the common mosaic of bearded iris and a mosaic of beardless iris differ from each other and from bulbous iris mosaic in host relations.

Gladiolus. Problems of disease control in gladiolus have multiplied as this crop has forged ahead in importance among florists' crops. These problems are discussed at the close of this account. Among Department contributions to the subject are Miss McCulloch's accounts of bacterial blight, scab, and Penicillium storage rot that have been mentioned above. She also studied the Fusarium disease in detail, and suggested soil treatment with chloropicrin as a control measure against the soil-borne phase. W. D. McClellan has outlined the symptoms of the Fusarium disease in leaves, corms, and roots, and has also shown that additional Iridaceous plants are susceptible. McClellan and N. W. Stuart have studied nutrient requirements of gladiolus and the effect of fertilizers on incidence of Fusarium rot. They find that nitrogen fertilizers increase losses due to Fusarium. McClellan, K. F. Baker, and C. J. Gould have pointed out that Botrytis gladiolorum is a low-temperature pathogen, causing leaf and flower blight in winter-crop gladiolus in Florida and corm rot where cool moist weather prevails at harvest. Brierley and Smith first showed that the mild mosaic of gladiolus is aphid-borne. McWhorter and L. Boyle showed that this mild mosaic of gladiolus is bean-yellow mosaic. The writer and Smith distinguished the white break disease, which is damaging to individual gladiolus plants but sporadic in occurrence. White break spreads in field plantings but the insect vector is not yet known. The aster-yellows virus was identified in gladiolus by Smith and Brierley.

ROSE DISEASES. The contributions of Miss Jenkins on brown canker and on Sphaceloma leaf disease of roses, as well as those of Miss Waterman on the Coniothyrium cankers, have been noted above. W. D. McClellan, who was familiar with rose mildew from research conducted before entering the Department, has called attention to the upsurge of this disease in greenhouse roses as syringing has been supplanted by aerosols for control of red spider mite. Brierley and Smith redefined the symptoms of rose mosaic, called attention to yellow mosaic types, differentiated mosaic symptoms from certain crinkle and speckle patterns in understocks not known to be of virus origin, and concluded that rose mosaic is spread in nursery practice rather than by insects in the United States. In the same paper they described rose streak, a necrotic virus disease likewise transmitted by tissue union only. They noted recently that rose mosaic is still present in forced roses but less prominent now because of changes in varieties. G. E. Yerkes, L. B. Scott, and C. F. Swingle determined that immaturity in Manetti understocks was responsible for some rose failures formerly confused with mosaic effects, and devised a starch test for maturity.

AZALEA DISEASES. A petal blight of cultivated azaleas was observed near Charleston, South Carolina, in 1931, and later was found from Texas to Maryland. Freeman Weiss described the pathogen as Ovulinia azaleae and worked out its life history and seasonal development. With Floyd Smith, he showed that bees and other insects may contribute to secondary spread of the disease, carrying spores for two miles or more. Early attempts at control by sanitary measures were unsuccessful. Miss Westcott showed Dithane and Phygon to be effective as protectant sprays. The writer found eradicants effective in suppressing apothecia, but practical applications of this have not been made. D. L. Gill has tested a wide range of protectants, confirming the effectiveness of

Dithane D-14 and adding Parzate and Dithane Z-78 as applicable against petal blight. Phygon has been discontinued as too injurious. Dusts are useful but they are less effective than sprays. Three applications of spray or dust per week during the flowering season are needed for good control of the disease.

DISEASES OF OTHER ORNAMENTALS. Camellia yellowspot, a virus disease transmissible by grafting, was described by J. A. Milbrath and F. P. McWhorter. Gill has determined Phytophthora cinnamomi as the cause of a wilt and root rot of camellia in nurseries. Brierley and Smith studied canna mosaic, finding the President variety immune. The same writers found carnation mosaic transmissible by Myzus persicae as well as by sap, and the Sweet William useful as a test plant for the virus. The streak disease of carnation is not transmissible by sap or by M. persicae, but natural spread occurs in outdoor plantings. They also established the cause of chrysanthemum stunt as a virus transmissible by sap and by grafting. Confusion and fear accompanied the appearance of the stunt disease in florists' chrysanthemums, but commercial control followed quickly after this proof of the nature of the disease. Mrs. Post reported a stem rot of dahlia caused by Macrophomina phaseoli. Brierley studied the mosaic disease of dahlia, distinguishing this virus disease from various insect injuries lumped with mosaic under the loose term "dahlia stunt". The mosaic virus is transmitted by Myzus persicae. Dahlia varieties vary widely in tolerance of mosaic, the more tolerant sorts serving the producer of cut blooms but acting as carriers in general collections. Dahlia ringspots, described by Brierley along with dahlia mosaic, are now recognized as symptoms of tomato spotted wilt. McClellan has shown that applications of chloropicrin or of nitrogen fertilizers, especially ammonium nitrate, afford some control of Sclerotium rolfsii causing crown rot of delphinium in Texas.

THE CONTROL OF NARCISSUS BASAL ROT

Before 1924 about 77 million narcissus bulbs were imported annually, chiefly for greenhouse forcing. In anticipation of quarantine restrictions imposed against narcissus nematode and bulb flies, and effective July 15, 1926, increasing numbers of bulbs were imported during 1924, 1925, and 1926, largely for use as planting stock to establish domestic supplies. Such imports reached 142 million bulbs in 1926. Several factors contributed to the rise of narcissus basal rot as a commercial problem at this time. In the first place many growers were unfamiliar with the culture of narcissus, or the Hollanders who undertook production in this country were unfamiliar with the climatic and soil factors encountered. Second, the cultures along the Eastern Seaborad from Long Island to the Carolinas encountered higher soil temperatures at harvest and at planting seasons, also higher temperatures during summer storage and shipment periods, than had been experienced in Holland. Third, the bulk of the stock planted in these early ventures was made up of very susceptible varieties, such as Golden Spur, Victoria, Spring Glory, Empress, and Emperor. Fourth, the hot water treatment, 110° F. for 2 1/2 hours, required for interstate movement if nematodes were found in the stock, proved an effective means of increasing basal rot. And finally, basal rot presented a new problem with little or no information available on cause, conditions of development or control. Basal rot was confused with the damage caused by nematodes and by narcissus flies, or with the Rhizopus rot that follows sun scald, or was attributed to overheating effects directly. Research on the disease was conducted simultaneously in England, in Holland, and in the United States, but the results of workers abroad were not available as a guide until the later stages of the problem.

A Fusarium was soon established by Weiss as the cause of basal rot. English workers later assigned it the name Fusarium bulbigenum, but American workers follow Snyder and Hansen in terming it F. oxysporum f. narcissi. This basal rot Fusarium is highly specific for narcissus, although closely allied forms attack other ornamental and vegetable crops. The trumpet varieties are highly susceptible, other classes, such as the Barrii, Leedsii, and Imcomparabilis, are somewhat less so, and the Polyanthus types are practically immune. However, the Polyanthus types are less hardy and therefore restricted to the warmer parts of the United States, and they meet an entirely different market demand. Trumpet varieties still dominate the cut-flower market, for forcing under glass or for cutting in the open field. It was noted early that trumpet varieties with hard bulbs, such as King Alfred, were less subject to Fusarium than the soft bulb sorts; but this difference is not a wide one. Although the extremely susceptible bicolors have nearly disappeared from commercial culture, King Alfred, still a leading commercial variety, has suffered severe inroads of basal rot in the East. A few Barrii varieties grown in North Carolina have proved less subject to Fsuarium but find limited market demand.

The development of basal rot is favored by moderately high temperatures, about 70° to 90° F., and is much slower at 60° F. or below. The Fusarium is originally introduced into fields in in-

fected bulbs, but it can persist in soil. In regions where high soil temperatures occur before the bulbs are dug, infection may take place from the soil and rot can progress further during storage. Also high temperatures after fall planting permit extension of incipient infections and lead to death of the plants in the field. In cooler regions, such as the Pacific Northwest, the Fusarium is relatively inactive in the soil and becomes a disease of storage and transit. As such facts became known growers changed cultural operations to minimize rot hazards. Such measures include rotation of plantings to avoid infested soil, early harvest of the bulbs, avoiding injuries in handling and overheating from exposure to bright sunlight or from massing moist bulbs in tight containers, quick drying of the bulbs after digging, careful sorting before and after storage, and storing in shallow layers in cool, well-ventilated storehouses. However, market demands call for susceptible trumpet varieties, and the warm soils of the East are conveniently accessible to markets. Hence research early turned to chemical treatment of the bulbs in the hope of checking the disease even where the climate and the varieties favored it.

Contamination of sound bulbs during the hot water treatment for nematode control was confirmed by Weiss, and the addition of formaldehyde or mercurials to the water was shown to prevent this. Inasmuch as hot formaldehyde is more effective against nematodes than hot water alone, an 0.5% formaldehyde bath has become standard. This treatment for nematode control also affords effective control of Fusarium in England, and supplementary fungicidal treatments against the basal rot fungus are not needed there. In America the hot formaldehyde bath for nematode control is infrequently required; but chemical measures against basal rot are needed each year. Therefore, extensive field trials have been conducted here over many seasons to determine the best fungicidal materials and concentrations, and the most favorable time to apply these.

Chemical treatments are feasible at two periods in the annual cycle of narcissus growth: (1) in early summer between harvest and storage, and (2) in the fall before the bulbs are planted. Prestorage treatments were tested and recommended as early as 1931 by Weiss; but the necessity of drying the bulbs again before storing, and the greater danger of chemical injury to only partially matured bulbs, made the preplanting period preferable for early screening tests with fungicides. Preplanting treatments proved relatively safe, and the treated bulbs could be planted at once without the necessity of special drying; but treating at this period, of course, offered little or no protection against loss during storage. From the first various mercurials proved superior. Mercuric chloride, calomel, Calogreen, Semesan, Ceresan, New Improved Ceresan, and other proprietary mercurials proved effective in reducing rot, but all caused some injury. Two standard treatments emerged, a two-minute dip in 2% Ceresan (1 lb. to 8 gallons) for the Northwest, and a similar dip in New Improved Ceresan (1 lb. to 40 gallons) for the warmer Eastern sections. Such treatments came to be widely used, and have been fairly credited with saving the narcissus industry in the East. Treated bulbs far outyielded the untreated, and mercury injury was inconspicuous and accepted as inevitable. Although commercial growers were reluctant to use prestorage treatments because of the danger of severe injury to flowers, heavy losses from basal rot in storage turned the attention of workers to such treatments once more. Weiss, Haasis, and Williamson have reported on such tests, and further extensive experiments by Haasis remain unpublished. In screening tests of fungicides for preplanting dips, only mercurials, and notably New Improved Ceresan, afforded effective control of basal rot during storage. A dip of 2 minutes duration proved as effective as a 5-minute or 10-minute dip in preventing basal rot, and the shorter dip caused less damage to flowers. Treatments applied soon after the bulbs were dug (3 days) provided best protection against storage rot but also induced maximum flower injury, whereas late treatment (15 days after digging) caused no flower injury but afforded little protection against rot. In current commercial treatment, bulbs are now dipped for 2 to 5 minutes 3 days after digging in the East, and 10 days after digging in the Northwest, with fair protection against rot and minor injury to blossoms.

Recently McClellan has shown that dips in Mersolite 8 or Puratized Agricultural Spray afford protection against basal rot equal to the Ceresan dips, with no flower injury. These organic mercury materials have come into commercial use as prestorage and preplanting dips in North Carolina. Prestorage dust treatments in place of dips eliminate the necessity of drying the treated bulbs before storing them. Ceresan dusts recommended by Weiss in 1931 did not find favor because of the hazard of inhalation of toxic material by workers. Similarly Arasan dusts advocated recently by McClellan cause skin irritation to some individuals. Injury to narcissus by mercurials varies in severity with the variety. It may take the form of surface discoloration or root-plate pitting in the bulbs that are treated, or it may suppress or deform the flower that is differentiated within the bulb before treatment, and which should complete development several months after treatment. Spectrochemical studies by McClellan and co-workers have shown that mercury is absorbed by the bulb and concentrated in areas that are most subject to injury, namely the center

and basal plate of the bulb and the developing shoot. McClellan and Stuart showed that basal rot is increased by heavy applications of complete fertilizers and by nitrogen fertilizers, particularly those carrying synthetic hormones or nitrogen bases. The causal Fusarium was stimulated by these organic nitrogen compounds when they were supplied in nutrient solution. Organic sources of nitrogen and excess nitrogen fertilization are now avoided by commercial growers of narcissus.

Summary: Twenty-five years ago Fusarium basal rot threatened to render narcissus culture unprofitable in the East. As research progressed cultural and storage practices were modified and fungicidal treatments devised that permit production of the crop even with relatively susceptible varieties and under climatic conditions favorable to the Fusarium. Basal rot is still present, causing some loss at times, but the security of the industry is no longer seriously menaced.

CONTROL OF DISEASES OF GLADIOLUS

The gladiolus has risen rapidly in importance during the past twenty years to occupy first place in market value among all florists' crops. The appearance of large-flowered long-stemmed varieties of good shipping quality expanded market demand and field production of cut blooms, until gladiolus appeared in every flower market, and in every month of the year in some. Such expansion of the gladiolus industry involves extensive shipments of planting stock and mass plantings in favored areas, two factors traditionally suited to dissemination and increase of diseases. As might be expected, disease problems have increased in number and intensity as the crop expanded. In 1916 L. M. Massey mentioned three diseases -- hard rot, dry rot, and scab -- as important in gladiolus. To these have been added Fusarium yellows and corm rot, Botrytis blight and rot, and Curvularia blight, which are major diseases, and a dozen other diseases of lesser or local importance.

Of the major diseases Fusarium yellows and rot caused by F. oxysporum f. gladioli, is a corm disease with secondary leaf yellowing. Botrytis blight (B. gladioli and B. gladiolorum), hard rot (Septoria gladioli), and scab (Pseudomonas marginata) affect both corms and leaves. Dry rot (Sclerotinia gladioli) involves a neck rot and corm rot. Curvularia blight (Curvularia lunata) affects leaves and flowers. The pathogens of all these diseases are corm-borne, and at least Fusarium, Sclerotinia, and the scab bacteria can persist in soil. Soil-borne diseases are avoided in part by rotation of fields, and often by moving to new land as long as suitable uninfested fields can be found. Chemical treatment of infested soils has not yet been applied commercially against these soil-borne pathogens of gladiolus. The production of disease-free planting stock has not been systematically developed, but corms produced in the cooler Northwest are prized for lower Fusarium infection. Sorting and chemical treatment of corms are not efficient enough to prevent introduction of pathogens into new areas, but are regularly used to reduce the severity of the corm-borne diseases. Preplanting treatment of corms has been intensively studied for years at several State agricultural experiment stations, and the New Improved Ceresan soak developed in Illinois has been of immense commercial value against Fusarium in Florida particularly, and in the East in general. Experience in Florida during the past year indicates that this New Improved Ceresan soak is providing less effective control than in former years, and that the problem is a continuing one. Cooperative studies by pathologists in several States have shown that different corm treatments are needed to cope with diseases that vary in prevalence in different areas. Prestorage treatments have been recommended recently from Florida. Spraying gladiolus for control of pests and diseases in the field was unheard of until the advent of the gladiolus thrips in 1930. Now Botrytis, Curvularia, and Stemphylium leaf diseases require regular applications of protectant fungicides, particularly in Florida.

Department studies, following the descriptions of diseases by Miss McCulloch mentioned above, have been concerned with factors affecting disease development, and with a search for disease resistance that can be used in a breeding program. McClellan, Baker, and Gould found the optimum temperature for the leaf blight phase of Botrytis to be 55° to 65° F., but corm infection was best at 35°, with little at 45° and none at 55° F. or above. Lack of corm infection at the higher temperatures is correlated with wound-periderm development which Ernst Artschwager and Ruth C. Starrett showed to take place most rapidly at higher temperatures and humidity. This behavior of Botrytis was found to be correlated with development of the disease in the field, areas with cool, moist growing periods proving to be subject to the foliage phase and those with cool, wet weather at harvest time experiencing Botrytis corm rot. The corm rot phase is now controlled in part by quick drying of the corms after harvest in areas with climatic conditions favoring Botrytis. Curvularia, on the other hand, is a disease of warm temperatures, the fungus having an optimum range between 75° and 85° F.

Studies of nutrition and fertilizer requirements of gladiolus by McClellan and Stuart have shown that the crop has a low nutrient requirement, and that excess nitrogen increases Fusarium

corm rot and bacterial scab. Organic sources of nitrogen increase Fusarium rot more than do inorganic, and a low ratio of phosphate to nitrogen favors rot development. Modifications in the use of fertilizer in commercial gladiolus culture have followed these findings. Greenhouse experiments show that Curvularia leaf blight is more severe in gladiolus plants that are furnished high levels of nutrients.

Resistant varieties are eagerly sought by gladiolus growers as the simplest and most effective means of disease control. A large number of gladiolus varieties have been supplied to the plant breeders of this project, S. L. Emsweller and R. L. Pryor, by Thomas Manley of the Garden Center of Greater Cleveland, and by the North American Gladiolus Council. These are being tested for resistance to Fusarium corm rot and to Botrytis, Curvularia, and Stemphylium leaf spots by W. D. McClellan in cooperation with R. O. Magie of the Florida Experiment Station at Bradenton. Some degree of resistance is available against the leaf spot diseases. Resistance to Fusarium promises to be most difficult to establish and to incorporate in commercial types. In Miss McCulloch's studies Picardy proved resistant, but Fusarium later became so virulent on this variety that the disease was called "Picardy rot". McClellan found various isolates of Fusarium to differ widely in virulence for different varieties, showing that strain variation in the gladiolus Fusarium is a complicating factor. Magie has recently reported that Maid of Orleans, long regarded as highly resistant, is now proving susceptible to Fusarium in Florida, and that no commercial variety is known to be immune.

In order to conduct valid tests for resistance it is necessary to establish conditions favorable for infection and development of the disease. The identity of the pathogen, its capacity for variation, its temperature requirements, and the effects of nutrition on the gladiolus and on the pathogen itself must be known to avoid the danger of confusing escapes with resistant individuals. As indicated above, some studies have been completed by McClellan and coworkers and others are in progress. Much further study is needed in order to standardize screening tests for resistance that will select the genotypes from which better varieties can be synthesized.

DIVISION OF FRUIT AND VEGETABLE CROPS AND DISEASES, BUREAU OF PLANT INDUSTRY, SOILS, AND AGRICULTURAL ENGINEERING, BELTSVILLE, MARYLAND

THE DIVISION OF FOREST PATHOLOGY

Carl Hartley[1]

Focused research on forest pathology in the Department began at the turn of the century. It was first conducted, along with some fruit-tree pathology, at the Mississippi Valley Laboratory, under Hermann von Schrenk. In 1907 it was transferred to Washington headquarters, under Haven Metcalf, where it included forest and shade trees and shrubs and became recognized as the central research organization in this field. Responsibility for ornamental shrubs was later transferred to the Division of Fruit and Vegetable Crops and Diseases. The work can be divided into three periods: 1899-1912, primarily reconnaissance; 1912-1930, continued search for undescribed diseases and evaluation of damage, but with emphasis on protection against introduced epidemics, and in the West the extension of research into the interrelations of silvicultural practice and diseases on the National Forests; 1930 to date, with continuing work on new or introduced epidemics, but more intensive effort toward adjustments of forest management practices to decrease losses in both the East and the West, and increased attention to the deterioration of forest products. A brief historical treatment of the entire subject of forest pathology, including the developments in Europe, which preceded those in North America, is supplied by Hubert (79, Chapter 1).

THE MISSISSIPPI VALLEY LABORATORY

The Mississippi Valley Laboratory was established about 1899 at St. Louis, Missouri. Von Schrenk was the only worker until 1902, when G. G. Hedgcock (148) and Perley Spaulding were added to the staff. A little later Ernst Bessey and Caroline Rumbold joined it. During the lifetime of the laboratory, von Schrenk, an unusually versatile investigator, with Cornell, Harvard, and Washington University background, published a number of pioneer papers on decays in timber trees (126, 127, 128, 129, 130, 133, 135, 137), much like Hartig's work in Germany one to two decades before. Later his interests swung increasingly to decays of structural timbers and wood preservation with chemicals (131, 132, 136). The first activities of the rest of the staff were on fruit-tree diseases, including pioneer work on bacteria as the cause of apple crown gall and hairy root by Hedgcock, and on bitter rot of apples by Spaulding. Later forest pathology received most attention. Staining of sapwood in trees and lumber by fungi and dips to prevent such staining during seasoning were followed intensively by von Schrenk, Hedgcock, and Rumbold (134, 63, 117). Spaulding pioneered the culture of wood-decaying fungi and started studies on control of damping-off of confier seedlings, the first to use successfully inorganic acids for this purpose. The first comprehensive American publication on forest-tree diseases was issued (138). Von Schrenk's attention to impregnation of timber with chemical preservatives led to the controversy with the Forest Service that contributed to the discontinuance of the Mississippi Valley Laboratory in 1907. He remained at St. Louis as a private consultant for railroads and others on wood preservation, in the development of which he has continued to take a prominent part.

THE DIVISION OF FOREST PATHOLOGY

After the discontinuance of the Mississippi Valley Laboratory, Hedgcock and Spaulding were brought to Washington to form the staff of the new Laboratory, later Office, and finally Division of Forest Pathology, headed up by Haven Metcalf (1, 105), with the large budget of $14,000. Metcalf was then 31 years old and had specialized on diseases of rice and sugar beets. A man of broad scholarship and impressive personality, an independent thinker with a keen wit and gift of expression, he quickly commanded the respect of cooperators and the loyalty of assistants. After 1910 his duties were so largely supervisory as to permit little personal research, but in the first decade after the formation of the Division he published numerous coordinating and educative papers, samples of which are cited (106, 107, 108). He was a leader in the early development of the American Phytopathological Society; and partly from botanical or plant pathological and partly from forest school scources he built up a staff that made its imprint on forestry and arboriculture as well as on mycology and plant pathology. The new alignment was made with the concurrence of the Forest Service, under an interbureau agreement by which the subject of wood preservation was recognized as the primary responsibility of that Bureau. Cooperative relations were good; a committee set up to insure effective cooperation between the two Bureaus found so little need for its services that in a few years it faded out. While the older plant pathology Divisions, including

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[1] A number of members of the Division have helped in the preparation of this paper, particularly Perley Spaulding, Glenn G. Hahn, George H. Hepting, and Agnes M. Ellis.

the original Laboratory of Plant Pathology under Erwin F. Smith, and the Divisions of Fruit Diseases and of Truck Crop Diseases that sprang from it, have all since been incorporated in the Divisions dealing with the culture of the crops, the Division of Forest Pathology has continued as an independent research organization devoted principally to pathology. Its continued independence has been due largely to the fact that there has been no single crop unit into which it could properly be absorbed. Silvicultural research is in another Bureau. Nut culture covers only a few of the trees dealt with in forest patholgoy. Little varietal selection or other research in shade trees has been done in recent years in the Department, except that which has been incidental to the studies in Forest Pathology. To have distributed the tree disease work to the different crop research units concerned would have made necessary duplication of attack on many of the diseases.

The major problem in 1907, largely responsible for first raising Forest Pathology to independent divisional rank in the Bureau, was the Asiatic chestnut blight, which had just been recognized as a potential devastator. Metcalf took personal charge of this work, initiating outside cooperation by part-time employment on it of J. Franklin Collins, Professor of Botany at Brown University, mechanical genius and expert on northeastern trees (144), and W. Howard Rankin of Cornell. Hedgcock was made responsible for a survey of the diseases on the National Forests, which he pushed with untiring energy. Spaulding took over the investigation of nursery and plantation diseases. He developed a broad acquaintance with European literature, which in 1909 led him to the discovery of the introduction and widespread establishment on pine in the Northeast of the white pine blister rust, which became the next emergency problem in the forest-disease situation. In 1909 Carl Hartley was added to the staff, and assigned to nursery diseases. In the same year C. J. Humphrey, at request of the Forest Service, was appointed; he was stationed at the Forest Products Laboratory of the Forest Service, for problems in the microbiological deterioration of wood. This arrangement for forest products has continued under the subsequent leadership of R. H. Colley and C. Audrey Richards for 40 years and resulted in the most intimate joint handling of commodity problems. The initiation of the next major line of activity of the Division was the appointment in 1910 of E. P. Meinecke, also at the specific request of the Forest Service. He was assigned to its San Francisco Regional Office, for adaptation of forest management practices to decreasing the incidence of heart rot and diseases in the National Forests and improving the salvage of infected stands. Meinecke had a wide background of European education and experience, including three years as assistant to Robert Hartig, founder of forest pathology. He promptly became a leader in constructive thinking in both pathology and silvics in this country. The outstanding success of this arrangement led to the appointment of J. R. Weir (153) and W. H. Long (154) to similar assignments in the Northwest and the Southwest respectively. The full-time appointment of Collins to shade tree disease investigation and inquiry correspondence, in cooperation with Brown University, in 1913, rounded out the organization of the work of the Division. An outgrowth of the shade tree work was cooperative disease survey and advisory work with the National Park Service, on the Parks, Monuments, and Cemeteries under its control. Emphasis in the epidemic diseases has been shifted from chestnut blight and blister rust to newer epidemics or threats of epidemics, which, under the successive leadership of R. Kent Beattie and Curtis May, have perforce received continuing attention.

Following the death of Metcalf in 1940, Lee M. Hutchins, known especially for his contributions to the physiology and pathology of fruit trees, was drafted in 1941 from the Division of Fruit and Vegetable Crops and Diseases to become Head of the Division of Forest Pathology. Under his leadership the strongly cooperative character of the work has been continued and extended. Active cooperation during the life of the Division has included not only the Forest Service, National Park Service, and Bureau of Entomology and Plant Quarantine, but also the Bureau of Ships of the Navy Department, the Housing and Home Finance Agency, Brooklyn and New York Botanic Gardens, Brown and Yale Universities, the New York State College of Forestry, the New Jersey State Department of Conservation, the Universities or Agricultural Experiment Stations of Idaho, Minnesota, Arizona, Georgia, Nebraska, Ohio, Pennsylvania, Maine, Wisconsin, Missouri, and Oregon and Pennsylvania and Kansas State Colleges. A beginning has been made at exploring the little-known field of virus diseases of forest trees (43, 47, 85, 155), on which in fruit trees Hutchins was the principal authority.

A recent summary of the situation of forest pathology is found in Hutchins' article in the 1949 Yearbook of the U. S. Department of Agriculture (84), which is followed by brief summary papers on each of the important activities. There are three American texts or manuals on the subject of forest-tree diseases (11, 4, 79), one of which (11) gives especially complete bibliography; and two that cover shade trees (36, 111). The picture as a whole is of an attempt to cover the diseases still largely in the reconnaissance stage that characterized the pathology of horticultural crops at

the beginning of the century and of field crops to a somewhat later date. Special focus on a few of the hundreds of host species has resulted in islands of quite thorough coverage, usually on points bearing on practical application, but frequently on phases that have fundamental scientific value.

In the strictly reconnaissance stage of the earlier years, Spaulding, Hedgcock, Boyce, and Beattie gave considerable attention to the pertinent mycological and pathological literature, both American and European. On the applied phases of the subject developed later, there was relatively little to be learned from the literature until quite recently, and attention to the literature has decreased, dependence being largely put on the Boyce index, the recent textbooks, and the excellent abstracts included in the Review of Applied Mycology. Card indexes developed by Spaulding and Hedgcock in early years at Washington, and more recently by Spaulding at New Haven, and by Boyce in connection with his manual (11), have aided other investigators. By a cooperative arrangement the Boyce index has been reproduced and sets have been furnished to branch offices of the Division. Formal extensive bibliographies on the chestnut blight (5), the Dutch elm disease (41), and diseases of cinchona (94a) have been published, and the three white pine blister rust bulletins by Spaulding carried bibliographies totalling several hundred titles (145a, 146, 147a).

Another valuable working tool is the reference collection of translations of important foreign-language articles in the forest pathology field, initiated by Gravatt during the 1930's. Languages such as Russian, Japanese, Dutch, and Italian, unfamiliar to most American pathologists, were particularly emphasized, and a total of 800 translations are now available for use. These and many unpublished reports are available for loan to active investigators of the subjects.

PRINCIPAL LINES OF WORK

FOREST NURSERY DISEASES: Though the total area of forest nurseries has never been large, their importance to the forest planting program and the applicability of intensive control measures in nurseries warranted special attention. Intensive studies and service activities mainly to State and Federal nurseries continued until 1920, and were resumed in 1935 at the time of the forest and erosion-control planting expansion on funds made available by the Civilian Conservation Corps and the Great Plains Shelterbelt Project. Most of the important nursery diseases then recognized were brought under a degree of control that made them no longer important limiting factors on planting operations. Exceptions included the Phomopsis blight of red cedar, which continues periodically to prevent the production of the stock required for field planting (29, 51), and some obscure root diseases. One of these was about to force the abandonment of one of the largest southern pine nurseries; recently it was found readily controllable by some of the soil fumigants employed for nematodes (92). Cedar blight is better controlled by mercurials than by other fungicides tried by Slagg and Wright, but requires too frequent spraying through the entire summer. Conifers have received the major part of the attention, since nearly all forest planting is with conifers and their diseases were causing more interference with production schedules than were those of the broadleaves. The finding in 1909 (54) that much so-called damping-off was due to heat lesions on the stem near the soil surface led to better seedbed management and stimulated recognition by foresters of high temperature at the base of the stem as a direct cause of much of the seedling mortality in natural forest stands. The recognition of a supposedly parasitic disease of older stock in some of the western nurseries as really an unusual type of drought effect, saved one of the early planting projects from discontinuance (53). The finding of an important relation of damping-off to soil nitrogen and pH, and its control on soils of intermediate pH by various inorganic acids, including orthophosphoric, and also by aluminum and ferrous sulfates, was one of the principal outcomes (29). One of the early indications of antibiotic action affecting a plant pathogen came out of the damping-off studies (55, pp. 82-84). The effect of the damping-off fungi on conifer seed was also demonstrated. The effort to protect southern pine nursery stock from the fusiform stem rust has led to an interesting development. Better control is obtained if a fungicide is applied to the burlap used to cover the bed while the seed is germinating as well as applying fungicide later to the seedlings.

NATIVE FOREST DISEASES: Loss from killing diseases in the forest, as pointed out by Meinecke (103), is not properly measured in terms of percentage of trees killed, but rather in percentage of the area of the stand that becomes understocked because of the disease. Damage also depends on whether the disease tends to kill the most vigorous trees as do the stem rusts, or the poorer trees as do most of the facultative parasites.

There have been notable contributions, particularly by pathologists at forest schools, but until recently the State Agricultural Experiment Station pathologists have left most of the job to

the federal government. This unfortunate hesitance has been partly due to the feeling in many quarters that nothing much can be done to prevent forest disease. The commercial forest area is greater than the area in cultivated crops, but unit values of forest land are relatively low. Against the cost of most disease preventive procedures there must be many years of compound interest charges before the timber is harvested. Intensive direct-control measures are rarely practicable. The use of fungicides, even in shade tree work, is relatively small (58). However, loss can nearly always be decreased by changes in forest management or utilization after the effects on disease of different timber management practices are sufficiently well understood.

In the West the early studies on the National Forests discovered or evaluated many unrecognized or little known diseases (64, 96, 101, 104, 164, 165). In the East, work on the native forest diseases advanced little until it became possible late in the 1920's to put pathologists at three of the new Forest Service Experiment Stations. At all of the stations maintained at the Forest Service field headquarters, a large amount of the attention has been to heart rots in the living trees (74). This is the most important single type of damage in old-growth forests, and is estimated as responsible for annual losses of 1-1/2 billion board feet of saw timber (2, Table 1). Information on the age at which decay can be expected to become serious helps in management planning. For example, Lake States aspen generally should be cut at 50 years of age, northeastern balsam fir at 70 years, and Appalachian scarlet oak at 120 years to avoid heavy cull. In some other species, decay is unimportant to a high age, except in stands of sprout origin or those injured by fire. Better acquaintance with external signs of heart rot makes possible more intelligent selection, bucking, and log grading and thus more economical utilization of infected stands (8, 102, 151, 73). Quantitative studies of the decay that starts at fire scars have also been applied to the establishment of fire damage claims (68) and decisions as to how much of the forest management budget should be allocated to fire prevention.

More important for the long pull, it has been found that by proper selection in thinning, or in selective logging of older timber, the more susceptible trees can be eliminated and heavy decay losses avoided in the residual stand. Trees are taken out if they already show signs of infection, or if they are bad decay risks. These would include trees that originated as sprouts from stump buds above ground line or that have large trunk wounds or large dead branches or mistletoe brooms through which decay can enter readily.

Such indirect approach to disease prevention, initiated by Meinecke in California (102), was early extended by Weir and Hubert in the northern Rocky Mountains (164), by Boyce in the Pacific Northwest (8), in the 1930's by Spaulding, Hansbrough, and associates in the Northeast (151, 150, 147, 16, 142), by Hepting, Lindgren, and associates in the oak type (115, 69, 67, 86), by Gill and Andrews in pine in South Dakota, New Mexico, and Arizona (3), and by Childs, Englerth, and Wright in the Pacific Northwest (166, 18, 35, 34). Parallel with these practical studies went the identification of the fungi that cause heart rots in a number of important tree species, in which, as with other diseases, the field workers were greatly helped by the intensive mycological studies of Davidson and associates (14, 15, 28) and by the Division of Mycology and Disease Survey at Beltsville. An unexpected development in a pine canker found due to a Fusarium, was the ability of the fungus to stimulate turpentine production when applied to trees artificially (71).

Another type of disease that could be decreased to an important degree by selection of sound crop trees in stand improvement thinnings, is that of the bark cankers, notably Nectria (42), Strumella, and others in eastern hardwoods (69, 67, 150). Nectria canker on yellow-poplar is one of the few well established cases in which forest trees can overcome established infections as a result of artificially improved growth conditions (in this case produced by thinning). Tympanis canker of red pine (52) is an example of the numerous diseases that are important only on trees planted outside the natural, or at least the optimum, range of the species; and in this case, even out of its range, damage can be mainly avoided by properly timed thinning. In this case, as in Valsa sordida canker of true poplars (11), Phomopsis lokoyae on Douglas-fir (9), and others, drought predisposes to infection. Nitrogen feeding, which greatly increases the incidence of damping-off in conifer seedbeds (55), at least temporarily cures the Phytophthora-associated littleleaf disease of shortleaf pine (116). This latter disease is important only on the less permeable soils (24), on which also the Phymatotrichum root rot is most severe in southwestern shelter belts. After further study, forest plantations can be safeguarded from such diseases by choice of species or geographic form appropriate to the site that must be planted, or conversely by choosing sites appropriate to the species to be grown.

Sanitation, in the sense of removing sources of infection, has not proved practicable in most of the cases for which it has been seriously considered. A trial of eradication of Nectria and Strumella cankers in oak was a failure.[2] The very destructive dwarf mistletoes (39, 88) of the

[2]Hepting, G. H., and Elmer R. Roth. Eleven years' results on canker control on the Swallow Falls State Forest, Maryland. 7 pp. (typed). 1944. Unpublished report.

Rocky Mountain and Intermountain Regions have been the principal exception to this. Elimination of old infected trees and pruning out new infections is a practicable protective procedure in many places (40). Another important exception is the use of fire. Prescribed burning has been shown very helpful against the brown-spot needle disease of young longleaf pine (140) and has been considered for removing old pine stands ruined by dwarf mistletoe and for completely cleaning out ribes from Idaho white pine land preparatory to new planting.

The numerous native rusts of conifers have received much attention. Meinecke, Hedgcock, Bethel, Spaulding, Weir, and Hubert did pioneer work in separating them and locating the alternate hosts of the heteroecious majority, recently summarized (10, 65). But removal of alternate hosts has not proved practicable for most of the rusts, even in the neighborhood of nurseries, and in the special case of the very troublesome Cronartium fusiforme on southern pines, Siggers (141), Sleeth, and Lindgren (91) have shown paradoxically that controlled burning or the removal either of infected leaders or of entire infected trees from plantations tends to favor rather than to prevent new infections in the residual stand. The bad effect of thinning or of pruning leaders results from the fact that the rusts, like other obligate parasites, are better able to infect the lush growth that follows these procedures. Other examples of predisposing effect of thinning have been found in the dwarf mistletoe of lodgepole pine (oral communication by the late Carlos G. Bates); and for a quite different reason, in Fomes annosus attack on roots and butts of white pine (72), in which the roots of the felled trees serve as feeder material for the Fomes. Sanitation procedures are unusually difficult subjects for experiment, since test plots in most cases must be so large that replication is expensive and intimacy of comparison is lost. They have not been extensively tested, and after more attention additional fields of application presumably will be found.

The work on virus diseases, previously referred to, has gone far enough to indicate that a thorough study will show the woods to be full of them. In locust (43) and also in elm, intensive study of one virus disease soon showed that others were also present. The locust brooming disease, and probably most native forest viroses, can be expected to become important only where vegetative propagation replaces the present practice of reproduction by seed.

Root diseases have been studied, but because of the obvious difficulties in both research and its practical application under forest conditions, no great advance has been made (112, 113). Most attention has been given the very damaging dwarf mistletoes of northern and western conifers (165, 88).

Interrelations between forest diseases and forest insects are numerous and often important. One of the surprising ones, first recognized by F. C. Craighead of the Division of Forest Insect Investigations, is the apparent need of the important scuthern pine bark beetle for the help of a specific associated Ceratostomella in its attack on the pine (118, 110). This fungus, C. pini, is practically never found except in trees attacked by beetles of the genus Dendroctonus, and is universally found with the southern pine beetle. Cooperative studies have indicated that the actual killing of the tree is by the fungus, after the beetle has done a thorough job of inoculating the tree with it; and that otherwise the trees would probably be able to drown out the beetle and escape the devastation that it often produces. While the practical problem of prevention remains with the entomologists, strictly considered it is merely a vascular wilt dependent on a specific insect vector. Somewhat similar symbiotic attack occurs in less-studied bark beetle-wilt fungus combinations that cause periodic devastations of large forest areas (118).

Resistance to native diseases is being determined cooperatively on the hybrid poplars and pines that the Forest Service is developing (20) and remarkable decay resistance of the wood has been demonstrated for two black locust selections of the Soil Conservation Service. Several factors, including the time required for the plants to reach seed-bearing age and the fact that most forest reproduction must be by natural seeding rather than by artificial seeding or planting, operate to keep the genetic approach in forest pathology from having as wide usefulness as it has in the case of food crops, and thus to remove one of the principal advantages of integration of cultural and disease research in a single Division. The genetic attack has larger possibilities for shade trees and will be discussed further in connection with introduced epidemic diseases. However, if forest or shade trees were made much less heterozygous in an effort to improve them, and particularly if this were carried to the point of making plantings of single clones, more rather than less disease damage would likely result (56).

NATIVE SHADE TREE DISEASES: The earlier work was perforce scattered and largely of a service type, because of the large volume of inquiry correspondence that had to be handled and the great number of tree species that it covered. Early attention was paid particularly to the art of tree surgery (23, 98, 38); Metcalf and Rush P. Marshall took the initiative in establishing and actively helped to develop the National Shade Tree Conference, an organization primarily of

commercial shade tree men, which has helped in the improvement of technical and ethical standards and the change in emphasis from cavity filling to more efficient forms of tree care and protection. Advances in knowledge have been chiefly in etiology and general hygiene (100, 97). A notable practical achievement was in the finding that the disastrous canker-stain of the much planted anthracnose-resistant London planetree could be stopped by simply restricting pruning to a safe time of year, or disinfecting pruners' tools and equipment (162). Susceptibility studies of shelterbelt plantings to Phymatotrichum root rot are mentioned elsewhere.

EPIDEMIC DISEASES, INTRODUCED OR OF UNCERTAIN ORIGIN (47): These have kept the center of the stage in both forest and shade tree disease work, particularly in the East, during a considerable part of the life of the Division. The periods of most concentrated research effort on the major epidemics were roughly: for chestnut blight, the decades following 1907 and 1924; for white pine blister rust, 1915 to 1925 in the East, and to 1940 in the West; and Dutch elm disease and elm phloem necrosis (155), 1932 to date.

Diseases that have appeared threatening but have received less concentrated or less prolonged attention thus far, include European larch canker, willow scab, the Cephalosporium canker of persimmon, Fusarium wilt of mimosa (66), the Nectria that kills beech weakened by the European scale (149), the Chalara wilt of midwestern oaks, the devastating dieback of birches in the Northeast, the pole blight of Idaho white pine, and the littleleaf syndrome of shortleaf pine. The last two are considered by their investigators at least as likely to be of native as of foreign origin.

Temporary epidemic threats, due to fungi that apparently are native rather than introduced, included the lokoya canker of Douglas-fir (9), and the Atropellis twig canker of hard pines (30). In addition, study was made in Europe by Hahn and Boyce of epidemic diseases that were feared as possible invaders of this country, but were found to be in fact native to North America and invaders in Europe (11, pp. 151 and 155).

Chestnut blight, caused by Endothia parasitica, has provided the spectacle of practical extermination of a widely distributed major species within a 50-year span. Metcalf early recognized its probable Asiatic origin (106). An eradication effort (108) was made in 1912-14 by the States of Pennsylvania and Virginia with cooperation by the Division. It became evident that even at the first discovery ten years earlier the fungus had spread too far to allow eradication. The disease reached the extreme limits of the range of the species within 40 years of the supposed date of first entry, killing most of the chestnuts in any particular locality within about 15 years after establishment. The numerous reports of comeback on the part of the chestnut have proved to be due to temporary escape, or the development of seedlings or sprouts for a few years in places where the old trees had been so completely killed that the fungus had died out locally from lack of a differential substratum and had not yet returned. Its more recent spread in Italy is causing concern (46).

The white pine blister rust, caused by Cronartium ribicola, (99, 107, 146, 90) entering independently on both East and West Coasts by or before 1910, has spread through nearly all of the range of the three commercial white pines, thus far causing little loss of timber of merchantable age but with much damage to young stands and indication that the commercial range of the two important western species may be considerably restricted by it despite all practicable control efforts. Of the other epidemic diseases, the most serious damage thus far has been to the beauty of numerous towns and cities by the two elm diseases and by mimosa wilt; the general dying of the commercial birch species in the eastern two-thirds of Maine; and losses of stumpage values estimated by the Forest Survey and Division of Forest Pathology at $5,000,000 per year from the littleleaf disease in shortleaf pine in the Piedmont. Oaks in places in Iowa, Illinois, and Wisconsin, beeches in places in the Northeast, and white pines in pole blight locations in Idaho have been hard hit; but the outcome of these and some others of the epidemic diseases listed can not yet be certainly estimated.

The first work on most of these epidemics was to determine their extent (37) and rate of spread, and whether they really were of foreign origin. In the case of chestnut blight and blister rust, some of the well known mycologists in the Northeast denied that they were of foreign origin. Therefore, the studies included Asiatic and European exploration and critical taxonomic and cross-inoculation studies, in some cases with monographic treatment of entire genera or parts of them: e.g. Shear et al. on Endothia (139), Hedgcock, Bethel, Colley, and associates on Cronartia found on Ribes (22, 64a), Hahn and Ayers on Phomopsis (48, 51), Adelopus, and Dasyscypha (50), Snyder et al. on the mimosa Fusarium (145), Lohman et al. on Atropellis and Nectria (93, 94), and Davidson on Ceratostomella (25, 26). The chestnut work included classical studies of means of transmission by F. D. Heald and associates (62), and study by G. F. Gravatt (45) and others of rate of spread that aided in planning utilization of the timber.

The larch canker bridgehead has apparently been destroyed by eradication. This was possible only because of the practical inability of the causal Dasyscypha to spread on the eastern larch in whose range the invasion occurred. This success, therefore, does not constitute evidence that eradication is likely to prove possible against really dangerous invasions from abroad.

White pine blister rust (99, 109, 146) is the one forest disease in which sanitation in the sense of removing infection sources has played an important role in local control. The eradication of the ribes (currants and gooseberries) that are the alternate hosts was started by Spaulding in 1909, and expanded into a campaign in 1916, under the leadership of S. B. Detwiler. After its practicability for control of the rust was demonstrated, its expansion was set up as a separate Division of the Bureau of Plant Industry in 1919, and transferred in 1934 to the Bureau of Entomology and Plant Quarantine, which has carried it on as a several-million-dollar program since that time. The numerous lines of research on the fungus, fundamental to the success of the sanitation program, were carried through by the Division of Forest Pathology, while studies of ribes ecology and methods of ribes control have been by the action agency. The eastern white pine, with the aid of the control program, continues to be a principal commercial species. The greater susceptibility of Idaho white pine, the greater cost of ribes eradication in some places in Idaho, and delayed availability of funds, have limited the area on which this species can be protected. Fire has been proposed as a last-resort method of reestablishing healthy stands in places. The rust has more recently invaded the region of the still more susceptible sugar pine in California and Oregon, where the results of control efforts thus far are encouraging.

The introduced epidemics have been the only forest-tree diseases for which there has been a serious attempt to develop disease-resistant varieties of trees (20). In elm, persimmon, mimosa, and white and sugar pines, enough resistance to their introduced parasites has been found to offer much promise. In the case of blister rust, contribution has been made to control by the discovery or promotion of varieties of cultivated Ribes that are immune or nearly so to the rust (49). In the case of chestnut blight and Dutch elm disease, interspecific hybridization has been employed to make use of the resistance of Asiatic species unpromising for direct forest planting, and the Asiatic orchard chestnuts and ornamental elms have been used directly. Selection will apparently provide an ultimate solution of the mimosa wilt problem. Interspecific pine hybrids developed by the Forest Service are also being tested against white pine blister rust.

An historical development on which the introduced tree diseases had a large influence was that of port inspection and quarantine. Until 1912 there was free trade in plant pests. There was no port inspection, and even if a dangerous disease were found on a shipment of plant material from abroad its destruction could be required only by the State Nursery Inspector in the State to which it was consigned. With the horrible examples of the chestnut blight and blister rust to aid him, Metcalf took a leading part, against the opposition of nurserymen who were importers and of some of the most prominent pathologists and mycologists of the time, in urging protective legislation. After the passage of the Simmons Act and the setting up of the Plant Quarantine Board, there was still hesitancy in establishing regulations that made full use of the powers conferred on the Board. In 1917 Metcalf, Detwiler, and R. Kent Beattie[3] were finally instrumental in getting provisions that could be reasonably effective in hindering the entry of foreign diseases on introduced propagating material. Few seed-borne diseases are known among forest and shade trees, and there is reasonable doubt as to the need for restrictions on seed movement. No action has been taken on the recommended requirement that logs generally be peeled before admission, the need for which was highlighted by the entry in unpeeled logs of the Dutch elm disease (6).

DETERIORATION OF FOREST PRODUCTS (57): One of the useful early reconnaissance activities in this field was on sanitary storage practices for lumber (80). During World War I there was a sudden expansion of work on the pathology of wood and its products. Problems were presented in the storage of paper pulp, the production of vehicle stock, and particularly evaluation initiated by Meinecke of the little-known discolorations and defects in airplane wood, for the study of which military funds were made available. These war needs brought into the products field C. Audrey Richards, R. H. Colley, and temporarily a number of others, and led to four Department or Technical Bulletins (76, 89, 125, 7).

The second expansion was in connection with the acute need for control of sapstain or blue stain of lumber that arose with the increase in the percentage of sapwood in the young-growth southern lumber in the late 1920's and the difficulty in selling sapstained lumber that was experienced particularly by the important lumber export trade. Partly with funds contributed by the exporters, products pathology work was set up in cooperation with the Southern Forest Experiment

[3]R. Kent Beattie came to Forest Pathology in 1912, but in 1913 went into the employ of the Board. He later returned to Forest Pathology.

Station of the Forest Service, under R. M. Lindgren. This promptly led to the finding of efficient mercurial and chlorophenolic dips for lumber and treatment for logs, the former being at once adopted by the industry, which within a decade was dipping approximately a sixth of all the lumber produced in the country, or about half of the lumber of the grades that needed it (124, 156).

The next large expansion of the products work was in connection with World War II, in which the need for a wider range of woods for aircraft required additional studies of discolorations suspected of being signs of incipient decay (119). Glues used in plywood, containers for military supplies, and safe construction and maintenance of wood training planes, gliders, ships, and war housing all posed problems that had not before been so acute. Since a large amount of unseasoned lumber was shipped, dipping was needed even more than during peacetime to prevent decay as well as stain during transit and storage. Furthermore, there was at times a scarcity of mercurials and chlorophenates on which stain control was mainly dependent. The number of questions that arose and the short time in which they had to be answered made the activity largely one of advising on the basis of existing knowledge or hasty and superficial tests. However, much was learned from the studies, as for example the importance of bacteria in protein glue deterioration (19), the decay resistance of different oaks (122), the significance of discolorations of aircraft woods (119), the demonstration that decay in aircraft was due not to moisture condensation but to avoidable failures in drainage (70), and the value of mixtures of fungicides, particularly with the addition of borax, in preventing decay as well as stain of green lumber, and at low concentrations that avoided skin irritation from the chlorophenates, made possible conservation of the chemicals (159).

Decay in buildings has received much intermittent attention and at present is a major interest because of the housing shortage, and some added hazards due to changes in construction methods and materials. The proposal by Scheffer and demonstration by Diller that frame houses without basements could be protected from the winter condensation moisture that leads to decay of sills and joists, by laying roll roofing on the soil surface under the house (31) was a particularly valuable contribution. The distinctive and destructive water-conducting capacity of Poria incrassata (82, 114) was one of the early subjects of study, followed by the more recent demonstration that it is surprisingly susceptible to drying (120, 121). While most parts of a building and even of a boat can be most simply safeguarded by protecting them from excessive moisture (157, 59, 75, 32), there are some parts that must depend on very high natural resistance to decay, or on fungicides. It is still difficult in many places to get lumber at retail yards that has had standard wood preservative treatment and the simpler dip or brush applications of fungicides that can be given in the course of construction have become of interest. These have been in laboratory tests and in outdoor trials on wood not in contact with the ground, under otherwise severe exposure conditions; while they are still to be regarded as makeshifts, tests thus far indicate that they have a considerable field of usefulness (157).

More fundamental contributions begun in the early cooperative studies with the Forest Products Laboratory included the relation between the decay resistance of the durable heartwoods and the toxicants in their hot-water-soluble extractives (61, 163). Basic contributions also included studies of decay diagnosis and classification (78, 27), reactions of decay fungi to temperature and toxicants (83, 60, 143, 77), moisture requirements for fungi in wood (21, 93), and improvement of methods for accelerated laboratory tests of the fungistatic value of new preservative chemicals (113, 81, 158) or combinations of these (33).

A field activity related to that of products pathology was the study of deterioration of killed timber in the woods, as an aid to planning salvage programs. Fire (87), hurricanes, insects, and chestnut blight have killed standing timber over great areas, and a number of quantitative studies have been made of the length of time during which the dead trees remain in condition to be utilized. Periods of usability have varied from 2 or 3 years in low-elevation conifers to 20 or 25 years in high-elevation conifers for pulp, and in chestnut for tannin extraction (12, 45). An unclassified activity that may also be mentioned is the study of the rate of decay of logging slash, a matter of much importance in forest management in some regions where it is desirable to have rapid decay and thus shorten the period in which the slash constitutes a serious fire risk. This type of study, pioneered by W. H. Long in southwestern pine and oak, has been extended to other types (152, 95, 17).

One of the contributions of the products pathology project is the part it has had in training men for later work for industrial concerns. Commercial effort in wood protection had previously been almost entirely by chemists and engineers. Pathologists formerly in the products work of the Division are now in responsible jobs with three of the companies that are pushing the newer wood protective chemicals, and in the industrial laboratory that has the largest concern in wood protection.

The following tabulation will serve instead of a summary, though it contains a few items not covered in the text.

Table 1. Summary of Forest Pathology activites.

SUBJECT Phases emphasized	Periods of special attention	Important findings or control developments
NURSERY DISEASES		
Damping-off of conifers	1907-20, 1933-41	Successful control by using acid soil and restricting nitrogen fertilization, or by treating soil with acids or acidifying sulfates; but not by withholding water.
Southern pines diseases	1929-date	Fusiform rust controlled by precisely timed spraying with organic fungicides, not by alternate host eradication. Needle brown spot easily controlled by Bordeaux; obscure root disease by soil fumigation with nemacides.
Other diseases, mainly conifer	1907-18, 1935-41	Correct diagnosis of a number of previously confused diseases led to control of most important ones except Phomopsis blight of cedar and certain seed failures.
NATIVE FOREST DISEASES		
Survey in West	1908-22	Numerous diseases discovered or evaluated. Life
Survey in East	1925-40	cycle of many heteroecious rusts determined.
Longleaf pine needle brown spot of seedlings.	1929-41	Control by fire as a sanitation measure.
Hypoxylon canker of aspen	1949-date	50 plots in Lake States in environmental relation study.
Septoria canker of tree poplars	1945-date	Many Forest Service hybrids tested for resistance; 19% appear resistant.
Trunk cankers, eastern hardwoods and red pine	1933-40	Selection of safer sites for plantations; release from competition for yellowpoplar and red pines; selection of low-risk trees for future crop.
Fusarium canker of southern pines	1945-date	Harmful to some species; stimulates pitch flow and may be useful in inducing commercial turpentine production from scrub pine.
Fusiform stem rust of southern pines	1930-date	Nearly disease-free stock for planting can be secured by nursery spraying and roguing. Pruning infected side branches from youngest trees; but not infected leaders.
Dwarf mistletoes, western conifers	1910-date	Recognition of magnitude of damage; removal of old trees that would infect young stands, and control of recent infection by pruning.
Sap streak, sugar maple, N.C.	1940-date	Endoconidiophora wilt; spread being studied.
Mortality after beetle attack, shortleaf pine	1928-31	Beetle-carried Ceratostomella the actual cause of death in bark beetle epidemics.
Cotton root rot, Okla. and Texas shelterbelts	1935-date	Least on sandy soils. Hackberry and junipers resistant; elms, legumes and American pines susceptible.

Table 1. (Continued)

SUBJECT Phases emphasized	Periods of special attention	Important findings or control developments
Native Forest Diseases (Continued)		
Root rots, western pines and Douglas-fir	1938-date	Etiology, effect on liability to bark beetles, and effect on stand density and yield.
Heart rots		Advances in etiology. Information on external signs of heart rot and relation of decay cull to age, making possible more intelligent harvesting of infected stands (firs, oaks, western hemlock). Practices for avoiding infection of young stands; fire control and careful logging to avoid wounds that decay can enter; in thinning operations the selection of low-risk trees as crop trees; and pruning lower branches of ponderosa pine before age at which decay can enter through them.
Pacific Coast firs	1910-28, 1945-date	
Eastern fir, oaks, yellowpoplar, black cherry, paper birch	1928-39	
Western hemlock and Rocky Mountain ponderosa pine	1933-date	
NATIVE SHADE TREE DISEASES		
Tree surgery	1913-46	Determination of best season for pruning; discouragement of too much cavity filling; Farmers Bulletin on tree repair and avoiding damage in construction work.
Canker stain of London planetree	1935-42	Control by observance of safe pruning dates or by disinfection of pruning tools and ethyl mercury nitrate in wound paint.
Wetwood in poplars, willows, elms, oaks, etc.	1932-39	Association with bacterial infection, increased wood pH, slime flux, and in Lombardy poplar early mortality.
Mosaics and brooming diseases	1928-30, 1937-date	Graft transmissibility demonstrated in locust, elm, and walnut; seed transmission in 2% of elm.
Verticillium wilt of		Can be partly controlled by fertilizing and watering.
maple	1923-28	
elm	1932-38	
Dothiorella dieback of elm	1932-38	Control by pruning.
Coniferous needle diseases in the Northeast	1940-48	Control by spraying.
EPIDEMIC DISEASES, INTRODUCED OR OF UNCERTAIN ORIGIN		
Chestnut blight	1907-	Endothia monographed to distinugish causal fungus from confusing relatives. Pioneer studies of dissemination. Pacific Coast infections eradicated. Rate of spread and of deterioration of killed timber studied as aid to salvage of old stands. Resistant Asiatic species introduced and crossed with American.
White pine blister rust	1912-45	Control by alternate host removal. Morphological and life history studies, to distinguish from confusing native species.

Table 1. (Continued)

SUBJECT Phases emphasized	Periods of special attention	Important findings or control developments
Epidemic Diseases (Continued)		
Dutch elm disease	1930-date	Introduction of "Dutch" disease traced to imported veneer logs. Insect transmission; route and rate of internal movement through the tree and external dissemination; new methods for elm propagation; discovery of resistant strains which are being multiplied.
Elm phloem necrosis	1930-date	
Phytophthora cinnamomi root rot	1933-40	Nineteenth century recession of chestnut, current decimation of Ozark chinkapin, and root rot of small numbers of other species connected with this fungus.
Littleleaf disease of shortleaf pine	1929-date	Relation to soil permeability, nitrogen deficiency, and abundance of Phytophthora cinnamomi; decrease in losses by adjusting cutting age on predisposing soils.
Mimosa wilt	1929? -date	Resistant clones now being multiplied; resistance transmitted by 50% of seed if from resistant trees.
Coryneum canker of Monterey cypress	1928-45	Cause determined and relative resistance of North American Cupressus species tested.
Willow scab	1932-40	Serious damage to some northeastern species; also now widespread in southern Appalachians. No intensive studies.
Dasyscypha canker of larch	1934-38	Found on European larch 20 years after introduction; low virulence on eastern larch; all known cases eradicated.
Pole blight, Idaho white pine	1949-date	Distribution in northern Idaho determined by airplane survey; etiological research in progress.
Birch dieback	1948-date	Devastating disease surveyed for distribution; associated ring spot exonerated; cause unknown.
Chalara wilt of oaks	1940-42, 1949-date	Cause determined, Survey started
Beech-scale Nectria disease		A weakly parasitic Nectria following scale infestation and causing widespread dying.
DETERIORATION OF WOOD AND ITS PRODUCTS		
Decay of logging slash		On most sites, decay is favored and period of fire risk shortened by slash disposal methods cheaper and simpler than those formerly prescribed.
Southwest	1913-18	
Northeast	1925-30	
Deterioration of killed timber		Determination of length of time during which the timber is worth salvaging. For Utah and Colorado beetle-killed spruce for pulp, and chestnut for tannin extraction and pulping, salvage plans materially aided by finding that utilization could continue for 20 years.
Hurricanes, Northeast and Northwest	1921-42	
Fire, Oregon	1930-40	
Fire, California	1947-date	

Table 1. (Continued

SUBJECT Phases emphasized	Periods of special attention	Important findings or control developments
Deterioration of wood (Continued)		
Insects, Utah, Colo., and Northeast	1947-date	
Felled for beetle control, Northwest	1922	
Chestnut blight	1923-33	
Decay of logging slash and deterioration of forest products		See last pages of text.

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DIVISION OF FOREST PATHOLOGY, BUREAU OF PLANT INDUSTRY, SOILS, AND AGRICULTURAL ENGINEERING

PLANT NEMATOLOGY RESEARCH IN THE BUREAU OF PLANT INDUSTRY, SOILS, AND AGRICULTURAL ENGINEERING

G. Steiner

ORIGIN AND HISTORY OF PROJECT

Nematodes were first observed to cause crop damage by Needham in England, who in 1743 discovered the so-called wheat nematode in galled wheat kernels. In this country damage related to plant nematodes is said to have been known in Florida as early as 1805, when galled and knotty malformations as they are produced by the root-knot nematode, were first noticed on roots of various crop plants. The causative organism was not discovered, however, until about three quarters of a century later. In the year 1889 the first three papers on plant nematology were published in this country; one by G. C. Neal on the root-knot disease of the peach, orange, and other plants in Florida, Bulletin No. 20, of the then Division of Entomology, U. S. Department of Agriculture; a second one by G. F. Atkinson, on nematode root-galls, Bulletin No. 9, of the Agricultural Experiment Station of the State of Alabama; and a third by F. Lamson Scribner, Bulletin No. 2, Volume 2 of the Agricultural Experiment Station of Tennessee. This last publication reports two different diseases of potatoes caused by unnamed nematodes. Today these diseases can be identified: one is that caused by the root-knot nematode, and the other that caused by Scribner's meadow nematode. In 1907 a separate unit for the study of plant and soil nematodes was set up in this Bureau with the establishment of a Division of Agricultural Technology. The major part of the work of this Division covered nematology investigations. The title of the Division was changed to Division of Nematology in 1928.

THE OVER-ALL PROBLEM

Nematology has been, and still is, a much neglected science. Nematodes are one of the largest taxonomic groups of the animal kingdom, but the least known from an over-all viewpoint. Aside from the parasites that attack man and vertebrates and a few forms attacking plants, they have never been made the subject of concentrated research efforts. The larger part of existing nematode species is still undescribed. This is particularly true of the marine forms and of those living in the soil. The present general conception of nematodes is, therefore, mainly patterned after what is known of the parasites of man and vertebrates. In reviewing the problems of nematology as related to crop production, it is thus necessary to point out that in this particular field, applied science has suffered more than elsewhere from a lack of comprehensive fundamental information. There exists here a diversity of basic taxonomic, morphological, physiological, bionomic, geographical, and economic problems that necessarily should be studied to implement the efforts for the control of noxious types of nematodes and also the attempts at a better understanding of other phases of the significance for crop production of the group as a whole. <u>The work under the present project of the Federal Bureau of Plant Industry, Soils, and Agricultural Engineering centers on the problem of crop and plant protection, particularly how to reduce losses and detrimental effects, and how to promote beneficial action of nematodes in this regard.</u> Adjunct activities cover such problems as that of the vinegar eel in its relation to the vinegar industry, or that of fresh water nematodes in drinking water supplies, or that of marine forms in disposal plants, and other similar nematode problems arising from the activities of man.

Progress of this nematode project has been hindered through the fact that the subject matter has not been taught until recently at colleges or universities. In addition the organisms involved are very small, yet highly complex and difficult to work with from a technical point of view. Furthermore, their life medium is the soil, an environment offering difficulties and complexities not found elsewhere. Finally, nematology, by nature a part of invertebrate zoology, requires, in its application to crop production, a knowledge of the principles of parasitology, plant pathology, soil science, and agronomy as well; this further complicates its study.

It should be mentioned that the Division of Nematology and a newly established unit at the College of Agriculture and the Agricultural Experiment Station of the University of California, are still the only agencies in this country dealing exclusively with these problems. The services of the Division of Nematology are required by Federal, State, and private agencies, individual growers, manufacturers of nematocides, manufacturers of equipment to apply nematocides or otherwise combat nematodes, and by others interested in related problems. The extent of these services may be measured by the amount of informative correspondence which annually numbers far over 1000 items, -- the bulk of them referring to control measures for plant nematodes.

Special mention should be made of the fact that the project includes services to regulatory agencies. Large numbers of nematodes are carried and distributed with plant material of any kind, such as food crops or nursery stock, and in soil and plant residues adhering to implements and conveyances. Certain plant nematode pests are the subject of special quarantines. The present project is to implement such quarantines and regulations and to help in their enforcement through identification of specimens found on imported plant material and other similar services.

As a project having primarily to do with crop protection against disease or otherwise noxious agents, the work program is subject to sudden changes. Unpredictable pest outbreaks and disease emergencies continually interfere in the pursuit of planned work and make the project in its phases highly changeable.

It is unfortunate that the greatest portion of our information on occurrence and distribution of plant nematodes is based on sample material submitted for examination and not on material collected methodically and according to plan. Thus our knowledge of plant nematodes is founded to a large extent on an accumulation of facts gathered by chance observations.

THE ROLE OF NEMATODES IN THE SOIL MAY WELL BE COMPARED TO THAT PLAYED BY INSECTS ABOVE THE SOIL

The annual loss to crop production caused by plant nematodes in this country, directly and indirectly, is estimated at between four and five hundred million dollars. This loss is primarily one of reduction in yield, but also includes indirect losses caused by the fact that nematode pests of plants frequently force the grower to rotations permitting cash crops only in periods of three or more years.

An estimate of the dollar value of the benefit nematodes cause by controlling noxious insects, slugs, and other organisms is not possible on the basis of available information.

The following table gives a breakdown of the project into its elements.

I. Nematodes as related to crop production and plant growth.
- A. Nematodes in their relation to plants.
  1. Nematodes as parasites of plants.
  2. Nematodes as carriers, distributors, and vectors of diseases of plants (bacteria, fungi, (?) viruses).
  3. Nematodes as secondary invaders of plants, i.e., following other primary disease agents; or taking advantage of weakened conditions due to other causes; or as part of a disease complex.
  4. Nematodes as controlling factors of plant pests: predatory forms, parasites of noxious insects, slugs, and other invertebrates.
  5. The enemies and diseases of nematodes.
- B. Nematodes in their relationship to the soil.
  1. Nematodes as members of the life association in the soil.
  2. Nematodes as related to the physical and chemical properties of the soil.
  3. Soil sterilization, soil disinfestation, and other soil treatments as related to nematodes.

II. Nematodes otherwise significant to the activities of man. (With exclusion of problems related to the parasites of man and other vertebrates.)

THE ELEMENTS OF THE PROJECT

1. NEMATODES AS PARASITES OF PLANTS: This is the principal subject of the present project. It is a problem of direct practical significance and it is for this reason that the project as a whole was initiated.

Wrong Approach to the Problem -- Early efforts in the study of these plant parasitic nematodes were completely over-shadowed by the search for control means. At least 90 percent of the literature on plant nematodes is written wholly from the viewpoint of control. The authors of the majority of papers of this considerable amount of literature never made a detailed study of the organisms involved nor did they have a basic knowledge of nematodes in general, of their structure, physiology, bionomics, classification, etc. This overemphasis on control had another unfortunate result: the repetition of the same or extremely similar tests and types of investigations, frequently with only a geographical or host variant. It was research lacking the basic tools.

Misconceptions That Caused Delay -- Because fungus and bacterial diseases are characterized by a quick and often killing action, it was long thought that plant infecting nematodes would present a similar disease picture. Plant parasitic nematodes, however, appear to live with their hosts in a high degree of balanced relationship. In other words, they try to live with their host plant, not to exterminate it. Their disease effect frequently is only that of reduced growth, reduced yield, or slow decline. They are a debilitation factor, a drag on crop production. This has tended to general underestimation of the pathological and economic significance of these pests.

Nematodes, with certain exceptions, are migratory disease agents. Parasitic forms need living host tissues to feed on. Frequently decay sets in where they have attacked and they are then forced to migrate to healthy tissues. Subsequent search of the necrotic tissues for pathogenic nematodes shows them absent or at best occurring in only small numbers. The wrong conclusion is then made, -- that the observed necrosis is not related to nematodes.

Disregard of the presence of plant-infecting nematodes in the soil has been the cause of failures in fertilizer tests, cover crop studies, and other experimental work. The interference of these pests with plant growth and yield thus has been the unsuspected source of confusing, and even of false experimental results.

What Has Been Done -- Today several hundred species of nematodes are known to parasitize plants. Of these some twenty are considered major crop pests. Certain of these pests have been the subject of more or less extensive studies, e.g. the root-knot nematode, the various bulb and stem nematodes (including the potato rot nematode), the golden nematode of potatoes, the sugar beet nematode, the nematodes causing spring dwarf and summer dwarf of strawberry plants, the nematode causing dieback in lilies, the chrysanthemum foliar nematode, the begonia nematode, the citrus nematode, the coconut palm nematode, various types of meadow nematodes, various seed-gall-forming nematodes, and many others. The root-knot nematodes are still considered the worst of these pests. Records are on hand reporting their occurrence in all but three States (South Dakota, Montana, and Rhode Island) of the continental United States. Since the species of this genus may cause specific symptoms such as swellings, knots, or galls on roots, they are the most easily recognized plant nematode pests and, partially for this reason, the best known and most intensively studied. Considered as among the worst agricultural pests the world over, their wide distribution and their significance as limiting factors in crop production are still greatly underestimated, even in our country.

Research on the root-knot nematodes has been more comprehensive than on any other plant nematode pest. Their life histories on certain hosts and also in regions of distinctly different climatic conditions, have been studied; their pathological effect on the hosts is to some degree known. Host strains and races have been found to exist. The phenomena of susceptibility, tolerance, resistance and immunity have been investigated, as well as modes of spread and distribution. Chemo- and hydrotherapeutic treatments for the cure of infected plants have been developed and tested, and, for the treatment of some hosts, found practical. Sanitation measures have been worked out and are today widely applied. Cultural control methods such as bare fallow, growing of trap crops, the use of immune and resistant cover crops, and the application of desiccation have been developed and evaluated by field tests. Control by crop rotation has been widely studied, taking into account regional and locational cropping methods and crop possibilities. Soil disinfestation has been the subject of special efforts. Treatments with heat (dry and moist) and chemicals have been tested. Liquid soil fumigants of volatile character have been found most promising in the control of these pests. Application methods adapted to a variety of crops, and regional and local conditions have been studied.

A few examples of accomplishments may be mentioned:

a. The fact was established that the roots, particularly the root tips, of certain so-called root-knot resistant or immune plants were invaded by large numbers of larvae of this nematode, but that these larvae were unable to grow in these roots and finally perished. Thus certain resistant or immune plants, e.g. Crotalaria spectabilis and marigolds, not only reduce a root-knot nematode infestation by starvation but actually trap and annihilate the nematode.

b. Field tests in a peach tree orchard demonstrated the possibility of a practical application of this remarkable host-parasite relationship. Trees of orchard plots with Crotalaria spectabilis as cover crop, during a period of six years, constantly yielded 6 to 12 times as many peaches as trees from plots with a susceptible cover crop. Trees of plots with a regular trap crop or with clean fallow gave yields constantly about halfway between the mentioned extremes.

c. The fact has been established that the root-knot nematode as conceived earlier represents a group of species each with different host range and reactions to climatic and other factors. It was shown by experiments, that, e.g. a southern species infecting potatoes in Florida and producing large protuberances on the potatoes does not withstand the rigors of winter here in Beltsville, Maryland; entirely different symptoms are produced on potato tubers by other species of root-knot nematodes. There are crops resistant to one species but not to others.

d. Establishment of the fact that there are plants highly susceptible to root-knot nematodes when young, but resistant when older (example: the tung tree).

e. It was shown that certain plants may be cured of a root-knot nematode infection by a hot water-formalin bath (e.g. peonies, tuberoses, black locusts), while others are not tolerant to such a bath (e.g. roses).

These and similar studies on root-knot nematodes were to a lesser degree duplicated on other nematode plant pests. As examples, there may be mentioned broad cooperative work on the golden nematode of potatoes, a pest discovered on Long Island, New York in 1941; investigations on the potato rot nematode occurring near Aberdeen, Idaho; studies on the nematode causing dieback in Easter lilies; investigations on nematode seed galls in Astoria bentgrass, in Chewings fescue, and other grasses; work with the narcissus bulb and the iris bulb nematode and the development in these instances of curative hot water-formalin treatments; studies on adaptation of these treatments to other plant nematodes and other hosts; work with meadow nematodes which attack a variety of host plants but particularly boxwood, potatoes, tobacco, olive trees, fig trees, and citrus; investigations on ring nematodes, on spiral nematodes, on the classification and identification of the cyst forming heteroderas; work on nematodes causing decline in mushroom crops; studies on nematodes causing "stubby" roots; investigations on the citrus nematode and many other similar problems.

2. NEMATODES AS CARRIERS, DISTRIBUTORS, AND VECTORS OF DISEASES OF PLANTS: A few authors have called attention to the fact that nematodes are carriers and vectors of other organisms. Little has been published regarding this matter. Extensive notes based on observations are in our files, but experimental work concerning this subject is almost completely lacking. The problem deserves consideration.

Nematodes, including plant parasitic types as well as others of the soil, have for some years been suspected to be vectors of so-called soil-borne viruses. This problem is at present being investigated in an exploratory way. Most significant is the carrier relationship between nematodes and bacteria. The large ecological group of so-called saprophytic and saprozoic nematodes clearly plays a most important role as distributors of bacteria. These latter may be carried attached to the surface of the body or more frequently in the intestinal tract of the nematodes. Less often fungus spores are distributed similarly.

3. NEMATODES AS SECONDARY INVADERS OF PLANTS OR OTHERWISE AS PART OF A DISEASE COMPLEX: Observations indicate that plants weakened by the attacks of other organisms or by climatic and similar causes are particularly attractive for nematodes. In these instances certain nematodes not considered parasites or pathogens of plants are observed as invaders. Planned research in this field is entirely lacking. It appears that not infrequently these secondary invaders are of importance, in preventing the recovery of a plant from the primary invader or disease cause, or in contributing materially to a final and rapid breakdown. There are many other phases of this problem and it appears that plant pathology eventually will have to approach these complex disease problems on a broad cooperative basis.

4. NEMATODES AS A CONTROLLING FACTOR OF PLANT PESTS: This problem relates to the question of how nature balances and controls nematode pests of plants. The known facts are as follows: There exist predatory nematodes which feed on other nematodes, particularly on those that attack plants. Evidence of this has been established by observations of actual predatory attacks, by a study of intestinal contents of certain predators and also by experimental tests. To what extent, however, natural control is thus established is not known. Attempts to colonize predatory types, such as certain mononchs, have not given sizeable results.

Nematodes, however, are notably parasites, and therefore a controlling factor, of such plant pests as noxious insects and slugs. Past work of an experimental character established the fact that the Mermithids, a large group of insect-parasitic nematodes, are a significant factor in a natural control of grasshoppers; where these Mermithids find desirable climatic conditions grasshopper outbreaks do not occur.

Another group of nematodes, the neoaplectanas, are very efficient controlling agents for soil insects, particularly the grub stages of the Japanese beetle, June beetle, and the white fringed beetle.

5. THE ENEMIES AND DISEASES OF NEMATODES: Enemies of nematodes are:

a. Mites, which have been observed feeding on agglomerations of specimens of the bulb and stem nematode. Such agglomerations, often containing thousands of larvae and called "nematode curds" or "nematode wool," have been seen completely consumed by mites. Similarly, egg masses and adult females of the root-knot nematode have been observed eaten up by mites.

b. On Long Island, New York, observations made in connection with the golden nematode of potatoes point to the possibility that small snails devour the cyst stage of this pest.

c. Tardigrades or bear animalcules have been seen feeding on nematodes.

d. Fungi-trapping and -catching nematodes were described by W. Zopf as early as 1888 and since then have been investigated by various authors. They appear to be one of nature's most effective control agents of nematodes in the soil.

e. Nematodes have their diseases; of these those caused by fungi, bacteria, and sporozoa appear to be the most important ones.

6. NEMATODES AS MEMBERS OF THE LIFE ASSOCIATION IN THE SOIL: The fact has already been mentioned that nematodes are extremely numerous in all soils having plant growth. Recent work in Europe demonstrated that there this group of organisms accounts for 99 percent of all the metazoans in the soil. Data on this matter are almost completely lacking for the soils in the United States. Recent counts in Switzerland showed the presence of from 2 to 18 million nematodes per square meter in the top 15 centimeters (about 6 inches) of cultivated and pasture land.

Soil science cannot afford to further ignore this component of soil life. It would appear that our present day conception of the biotic complex in the soil is at least largely incomplete if not erroneous through the one-sided consideration of only earthworms, bacteria, fungi, and noxious insects. The interrelations between these various components are also largely unknown.

7. NEMATODES AS RELATED TO THE PHYSICAL AND CHEMICAL PROPERTIES OF THE SOIL: Light sandy soils are preferred by certain plant parasitic types (root-knot nematodes). How far this preference applies to other forms is not known. It has been demonstrated, however, that certain nematodes are specific to muck soil, to peaty soils, to leafmold, etc. It is thought that additional information, particularly if based on planned and experimental work, might furnish valuable facts to be used in rotation schemes and in cropping methods. The significance of nematodes as a factor in breaking down organic material in the soil is another phase that has been overlooked. Furthermore, to what degree and how are the millions and billions of nematodes in a given soil of significance for its air and gas economy?

8. SOIL STERILIZATION, SOIL DISINFESTATION, AND OTHER SOIL TREATMENTS FOR NEMATODE CONTROL: The most important procedure in the control of plant nematodes is their elimination from the soil. There are no soil treatments known at present, however, that are exclusively nematocidal. The various soil treatments that give efficacious nematode control also eliminate other soil organisms to a certain degree. This is most often an additional advantage, since as a whole the biotic complexes in our crop lands are crop-antagonistic. The problem of soil treatments is, therefore, only partly one of nematode control. It has also a fungicidal, algaecidal, bactericidal, and insecticidal phase and involves other soil organisms, soil chemistry, and soil physics. As a research subject it therefore requires cooperative work.

Complete soil sterilization is not practical, and in nematode control work is used only in experimental set-ups. Steam is a most effective agent against nematodes but is practical only in greenhouses, seed beds, and small field areas. It has the advantage of penetrating into cracks and roots, thus exterminating nematodes most effectively.

Soil disinfestation by means of chemicals has become the most promising method of eliminating nematodes. Toxic gases are not satisfactory because their application involves too many difficulties. Solids have not given very good results, apparently because it is difficult to mix them evenly with the soil. Most outstanding progress has been made with volatile liquids, commonly called soil fumigants. Such materials were first tested some 80 years ago to cure "soil sickness"

or "sugarbeet tiredness" of a soil infested with the sugar-beet nematode. The nematocidal action of carbon disulfide was discovered at that time and although many hundreds of chemicals have been tested since, it is still used as a soil fumigant. Its nematocidal action is good but its explosive features make it unfit for general use.

Trichloronitromethane (chloropicrin or tear gas) came into use after the first world war. It was the first chemical used in large scale field fumigation but proved economical with high priced crops only. Through the recent discovery of the nematocidal action of such compounds as dichloropropene and dichloropropane mixtures (Shell D-D, Dowfume N), as 1, 2 dibromoethane (ethylene dibromide, Dowfume W, Iscobrome D, Soilfume, Bromofume), as bromomethane (methyl bromide, Iscobrome 1, Dowfume G), large scale field fumigation has been made practical. Over 100,000 acres of crop land are annually treated for nematode and wireworm control in the United States. Marginal, infertile land has been brought back to full fertility through soil fumigation. Land so treated appears always to produce better growth of plants. The case of the greatest yield increase yet observed as a result of soil fumigation may be cited. It involves a planting of sweetpotatoes which were attacked by root-knot nematodes and wireworms. The yield on treated land was seventeen times that of the untreated. Double and triple yields as a result of soil fumigation are not uncommon.

To reduce costs, several short-cut methods of soil fumigation have been tested and proven economical. For example: the spot" treatment" in the case of widely spaced crops such as watermelons, the "planting site treatment" in the case of shrubs and trees (a circular area of 3 to 6 feet in diameter is fumigated), and the "row treatment" in cases of widely spaced row crops (only the row to be planted is treated). Protection of the roots of the young plant is thus established. These short-cut methods permit the formation of long feeder roots and thus give the plant an enormous initial advantage. Any later invasions by nematodes would have a far lesser disease effect, confirming an old grower's saying, "first roots, then shoots."

The problem of mechanically applying fumigants to the soil most effectively has also been attacked. Numerous machine and hand applicators of various types have been constructed and are constantly being improved; applicator attachments to tractors and plows are already in use, some of homemade construction being built of second-hand spare parts. Thus we have today some very efficacious nematocidal soil fumigants permitting a per acre treatment at a cost of from $20 to $70, and these fumigants are easy to handle and not dangerous. A beginning has therefore been made in control by practical means of the many underground pests, paralleling the much more advanced methods of spraying, dusting, and fumigating of the above-ground parts of our crops and plants. A wide field for research of significant practical possibilities has thus been opened.

Other practices aiming at an elimination of noxious nematodes include crop rotation. In this case the attempt is made to exterminate certain nematodes by depriving them of their host plant. The application of heavy mulches is claimed to reduce infestations of the root-knot nematodes. Mulches appear to promote natural enemies of these nematodes, particularly nematode-trapping fungi. Flooding of land over long periods also reduces a root-knot nematode population; exposure to the hot sun and desiccation have a similar effect. The satisfactory use of these and similar treatments depends largely on possibilities of local conditions.

WHAT IS TO BE DONE

The answer to this question requires first an identification of the goal to be reached. This goal is obviously the elimination of all inimical interferences by nematodes in crop and plant production. It appears that a final solution of the problem would involve the complete eradication of all noxious nematode types. Such a solution is not in sight, not even in the case of individual forms such as the golden nematode of potato. In this country, this pest occurs in a single and restricted area, and would therefore appear to offer a simple eradication problem. This, however, is not the case. The next best definition of our aim would be "to find and develop the best methods, treatments, and procedures to reduce to the lowest possible degree the noxious interference by, and to promote the beneficial action of, nematodes in crop and plant production." This goal is primarily an economic one, and an acceptable work program pertinent to the project must primarily consider urgent disease and pest control needs. Longtime broad fundamental research enters the program as a second subject and may be considered after the primary economic needs are satisfied. Proper work planning should carefully evaluate the significance of each in any single program item. In this connection it is of interest to mention that during the past years the requests for urgent control of plant nematode pests have steadily increased so that less and less time could be devoted to fundamental problems. This, possibly, is due to two reasons: first, growers and investigators are becoming more familiar with plant-nematode pests;

and second, plant-nematode pests are rapidly and extensively distributed through human activities. It has already been emphasized that any work program set up in a project dealing with diseases and pests of the present type is variable in character and subject to unforeseen changes and delays, since pest outbreaks often present an emergency.

In a work program covering the present project, therefore, two main phases must be considered:

1. The existent pest and disease situation with which we are confronted, to be taken care of with the known control means.

2. The promotion of basic knowledge on a broad scale to better implement the handling and control of nematodes for the advancement of crop and plant production.

In the first phase primary importance should be given the proper identification of nematode pests of plants, the gathering of information on their occurrence and distribution and the evaluation of their significance. This is to be supplemented with dissemination of information on the subject and with the formulation of control recommendations.

Considering the specialized character of the subject matter and its inherent difficulties and complexities, it should be handled by trained specialists. Problems and pests of the present kind should be studied where they occur and control measures should be worked out on the basis of local conditions and cropping methods. This necessitates the establishment of a network of regional laboratories. Personnel at these laboratories work primarily on regional pest and disease problems in close cooperation with the growers and producers. Control work is a primary function. At present such laboratories are established at the following locations: Georgia Coastal Plain Experiment Station, Tifton, Georgia; Salt Lake City, Utah; Western Washington Experiment Station, Puyallup, Washington; Hicksville, Long Island, New York; Central Florida Experiment Station, Sanford, Florida; and Nematode Field Laboratory at Sacaton, Arizona. More are necessary to accomplish adequate service.

Phase two of the work program embraces the basic research. A diversity of subjects needs attention; preference is given to problems of immediate need from a pest control viewpoint. Examples of program items are: Work on soil fumigation, specifically a continued search for superior fumigants and improved application methods. Studies concerning the physiological action of these fumigants on the nematode organism and also their effect upon the soil and crops, and particularly the quality of food crops in conjunction with annual or other periodical fumigation. Basic work on specific pest problems such as the golden nematode of potatoes, the potato rot nematode, the root-knot nematodes, the sugar beet nematode, the citrus-nematode, seed-gall forming nematodes, spiral nematodes (*Helicotylenchus*), ring nematodes (*Criconematidae*), lance nematodes (*Hoplolaimus*), pin nematodes (*Paratylenchus*), spear nematodes (*Dorylaimus*), and numerous other types. Meadow nematodes (forms of the genus *Pratylenchus*) are increasingly recognized as extremely serious root parasites and appear to be of significance in various hitherto obscure diseases of ornamentals and crops, particularly the slow decline and dieback observed in certain orchards. These forms are little known; basic information concerning their structure and bionomics is badly needed.

THE UTILITARIAN ASPECT OF PLANT NEMATOLOGY RESEARCH

Since the present project is carried on with public funds a few remarks on the utilitarian aspect of this research appear appropriate. Annual appropriations are the investment, the dividends consist obviously in yield increases through control of plant nematode pests. However, this would be a rather incomplete calculation of the returns from the investment. It is evident that research under the present project produces profits not restricted to crop gains, but that other human activities and aims also benefit. Chemical industries and engineering, e.g., are involved through the manufacture, promotion, and application of soil fumigants. It is estimated that the present annual value of soil fumigants manufactured for nematode control amounts to at least $5,000,000. Machines and apparatus for the application of these fumigants also have to be considered, and likewise the experts that handle and promote this type of specialized work. Even the pursuit of certain hobbies may be mentioned in this connection, as e.g., the artificial production of the nametode (*Panagrellus*) on yeast cultures for fish food. Of more significance is the growing of house plants, many of which, such as the African violet (*Saintpaulia*), present specific nematode problems. Cut flower production and the whole nursery industry certainly benefit from the present project through additional income estimated several million dollars. Repeatedly, success of such an enterprise has depended on nematode control as, for instance, in the case of a war veteran who specialized in the production of tuberoses. Inroads by nematodes threatened complete failure which eventually was avoided through work under the present project.

Another example is furnished in the production of narcissus bulbs and flowers. The narcissus bulb nematode at the time of the first world war threatened complete destruction of commercial narcissus plantings. Research has enabled the industry to control this nematode and to live with it. A related nematode pest, the iris bulb nematode, during recent years threatened the production of bulbous irises in the Pacific Northwest. Work under the present project has re-established full production and is estimated to save the growers annually about $200,000. These last two examples further demonstrate another utilitarian phase of the present project, i.e., the promotion of home production versus foreign production and imports.

It should also be pointed out that with the growth of our knowledge of plant and soil nematodes, utilitarian objectives are more easily accomplished. As an example the discovery of a spawn-destroying nematode in mushroom beds may be mentioned. The identification of this nematode suggested immediately the pattern of control methods to be tested. Thus, previous experience with related nematode types brought about a cumulative utilitarian effect.

Concerning pest problems of recognized magnitude such as that of the root-knot nematodes, which is not only nation-wide but global, the annual savings resulting from work under the present project are estimated at millions of dollars for this country alone.

In the control of the sugar-beet nematode, a pest that in the early days of the beet sugar industry seriously threatened it, the annual savings are estamated at several hundred thousand dollars.

Finally, mention should be made of the fact that scientific work in other fields also benefits from progress of the present project. Particular reference is made to experimental studies on soils, specifically on fertilizer applications, also to tests of the plant breeder. Proper consideration of the factor "nematodes" in any soil used for such experiments may condition success or failure of such experiments.

Thus it is evident that benefits from the present research are quite diverse and that the project not only consumes tax money but also produces taxable income.

DIVISION OF NEMATOLOGY INVESTIGATIONS, BUREAU OF PLANT INDUSTRY, SOILS, AND AGRICULTURAL ENGINEERING

THE PLACE OF THE PLANT DISEASE SURVEY IN PLANT PATHOLOGICAL INVESTIGATION

Paul R. Miller

The Plant Disease Survey, for many persons, is practically synonymous with the Plant Disease Reporter, and more recently with the Warning Service. These most conspicuous and widespread services tend to obscure the Survey's own original contributions to plant pathological knowledge. The Reporter and the Warning Service are very obviously necessary to the proper performance of the Survey's best-known functions. The primary importance of "survey" research to certain kinds of problems is perhaps less evident, but it is no less closely connected with Survey objectives. The following account is designed to bring out the relation of these two aspects of the Survey work to each other and to plant pathology in general.

FEATURED SERVICES OF THE SURVEY

First place among the contributions of the Survey to plant pathology must be given to the Plant Disease Reporter. We must admit that we are proud of the Reporter and always give it right-of-way in our work. Best-known and longest established of the Survey's informational services, it was founded, as the Plant Disease Bulletin, in the first year of the Survey and has continued ever since, receiving its present name in 1923 (with volume 7). In its 34 years (1950, volume 34) the nature of its contents has changed considerably to correspond with plant pathological needs, interests, theories, and knowledge. In response to demand for a more permanent format the method of publication was changed from the original mimeographing to multilithing beginning with this year. This change has increased the usefulness, durability, and, not least important, the attractiveness of the Reporter immeasurably.

Of course the Survey cannot claim all the credit for the Reporter, since its contributors are responsible for the contents that make it so useful. Its greatest value is that it makes possible the prompt reporting of results and discoveries while they are still news, with detail enough for full understanding but without necessity for the thoroughness demanded by a complete presentation, which indeed should receive more formal publication.

The Supplements are an adjunct to the Reporter, for long articles or for material that is most effective when presented as a unit. Subjects of the Supplements are too numerous to list; some of them are quarantines, State lists of disease occurrence, diseases in foreign countries, market diseases, a series on cereal rust epidemiology and importance in the 1930's, the Survey's annual summaries of plant disease occurrence and the crop loss estimates, summaries of the Warning Service, forecasting, the summaries of results with new fungicides that were of use to both pathologists and the fungicide industry. Most recent are this series on plant pathological investigation, and Dr. K. Starr Chester's pioneer work on loss appraisal (7).

Between the earlier "Check List of Plant Diseases in the United States", issued in 1926 (1) and the new "Index" currently being published (40), 14 years have gone by. In the interim, plant pathologists have greatly increased their knowledge about occurrence and cause of plant diseases, but so have plant diseases increased in number and distribution.

The Warning Service was established recently as a logical outgrowth of the Survey's information function. It will be discussed in its chronological setting.

Of the Survey's numerous other informational tasks, only one need be mentioned: a monthly article on plant disease news compiled for publication in a chemical trade journal from the contents of the Reporter.

THE SURVEY'S CONTRIBUTIONS TO PLANT PATHOLOGICAL KNOWLEDGE

In a discussion of Survey work, it soon becomes evident that "Plant Disease Survey", as an organization, really has two easily distinguished meanings. One is general; it includes all the collaborators and other cooperators of the Survey. The other "Survey" is specifically the small official Survey staff.

A major part of Survey accomplishment is due to the inclusive organization. Not the least of its contributions, although mostly rather taken for granted, is the fundamental information on plant disease occurrence and importance acquired since the Survey was founded.

One method of adding to knowledge is to compile known facts in such a way that significant features are brought out clearly. Much of the Survey's contribution is of this nature -- always cooperative, of course. Typical examples are the crop disease hazard survey (32), the recent report on effects of losses on agricultural industries and on farm life (41), and the soil infestation

survey (21). In all of these the information already existed but in separate isolated pieces; bringing it together gave it meaning and emphasis.

The reports on the results of the warning service (22, 24, 28) are further illustrations of this category. Each analyzes all the information obtained during the season; while the series is an outstanding contribution to the epidemiology of the diseases concerned.

These and other accomplishments of the inclusive Survey (we might add this series on plant pathological investigation in this country) are important; they give spatial and temporal perspective to plant disease study.

In its restricted sense, the Survey has taken its part in original investigation of plant pathological problems. N. E. Stevens (33) has stated the place of survey work and survey methods (not necessarily "Survey" with a capital "S") in research. His discussion emphasizes the generally undervalued role of observation. Research implications of the results of the Emergency Plant Disease Prevention program have been reported by ourselves (19, 27) and by others (5, 8). The Survey is currently responsible for various research programs under the Crop Plant Disease Forecasting Project, which will be described briefly in a later section.

Many of the Survey's special studies are mentioned briefly in their various chronological settings. Among them, two are of such different types, serving such diverse purposes, but each so consistent with Survey objectives and so characteristic of Survey investigation -- indeed they could only have been accomplished by survey methods regardless of who performed the actual work -- that we report them in some detail. The first was a pioneering venture and its achievements are still unique. The other is an illustration of the necessity for survey aid in a widespread disease control problem.

Parenthetically, we might remark that Survey investigation is mostly preliminary to further work by others, and often enough the starting point is overlooked in the final result.

THE KNOXVILLE MARKET AND KITCHEN DISEASE SURVEY: Although diseases affecting harvested crops at shipping points, in transit, at destination, and in storage, have been the subject of much study, very little is known about losses suffered by distributors and consumers. The Knoxville market survey in 1934 and 1935 was planned in cooperation with the University of Tennessee, as a beginning toward obtaining some adequate information as to the actual extent of such losses. It involved the determination of the origin, kind, and amount of plant food products that were brought into Knoxville, how they were shipped, where they were delivered, their condition on unloading, length of time between unloading and receipt by wholesalers and between wholesalers and retailers, type of handling received in all these stages, and the causes of decays and blemishes.

Carefully planned advance publicity through radio talks and newspaper writeups explained the reasons for the survey. The amount and quality of the cooperation obtained in later personal visits to distributors and homes was evidence of active interest in this subject.

Cooperators, both distributors and consumers, were furnished forms on which to keep records of fresh fruits and vegetables bought and of the amount discarded because of spoiling. Colored photographs of diseased fruits and vegetables (issued by the Bureau of Agricultural Economics and the Bureau of Plant Industry) increased distributors' understanding of the survey, and it was emphasized that their own records of such losses constituted a part of their profit and loss inventories. Consumers were given a chart with pictures and descriptions of some of the most common market diseases and a diagrammatic explanation of plant disease attack. Causes and extent of loss were checked in periodic visits by the investigators.

Procedure and results of this first comprehensive city-wide market disease survey were reported in Supplement 88 (14). Perhaps not the least important result was the understanding that cooperators obtained as to the nature of spoiling and the methods of handling needed to reduce losses.

COTTON SEEDLING DISEASE AND BOLL ROT SURVEY: The essential role of field information in the solution of some kinds of disease control problems is illustrated by the cotton seedling disease and boll rot survey conducted during the four-year period 1938 to 1941 by the Plant Disease Survey in cooperation with the Division of Cotton and Other Fiber Crops and Diseases.

Chemical seed treatment was effective in the control of certain seedling diseases, but much waste accompanied its use because the identity, distribution, relative importance, and epidemiology of the organisms involved, as well as their possible connection with organisms associated with boll rots, were known only to a limited extent. The only way to acquire this information was through a correlated regional survey throughout the cotton belt from the Atlantic Coast to Texas and Oklahoma, including not only field observation but laboratory and field study as well.

Means employed included counts and collection of over 2,000 samples taken in 14 States in numerous fields, laboratory identification of organisms associated with diseased seedlings and infected bolls, study of plants grown from infested seed at different locations under different con-

ditions, determination of sporeloads on the seed, and investigation of the possibility of seed contamination during the ginning process. Entrance of this country into World War II prevented continuance of the survey, but at the same time it made even the foreshortened results all the more important because of the more definite basis for control of seedling diseases and consequent reduction in waste of effort and material.

Results included: 1 -- The anthracnose fungus, Glomerella gossypii, which was thought to have become a minor factor, was found, on the contrary, to be widespread throughout the Southeastern States. It was isolated from four-fifths of the seedling disease samples and two-thirds of the boll rot samples, and was by far the most frequently occurring pathogenic organism in both. 2 -- Discovery that anthracnose symptoms on affected bolls were entirely dissimilar to those described in classic earlier work on this disease explained the general non-recognition of its presence. The difference in symptoms probably followed the introduction of the boll-weevil and the consequent adoption of varieties with a more open type of growth, not conducive to the development of the earlier-known symptoms. Evidence was also obtained indicating that insect punctures and prior infection by Xanthomonas malvacearum favored infection by Glomerella, further confusing the symptoms. 3 -- Results of seed treatment had indicated that seed was the principal source of seedling infection, but the amount of seedling anthracnose infection determined during the survey was much larger than would be expected from the number of bolls observed to be infected with Glomerella. In specific investigation of this discrepancy it was determined that "trash", including broken parts of the cotton plant or debris picked with the seed cotton, may carry more spores than the seed. In the thorough mixing of the ginning process the seed is likely to become contaminated with the fungus, even though ginning removes most of the trash. The degree of seed contamination depended on that of the trash. Carry-over of contamination in ginning from one seed-cotton lot to the following lot was also demonstrated. Thus it was concluded that contamination of the seed in ginning was responsible for much of the damping-off due to Glomerella infection. 4 -- Glomerella was abundant in the southeastern part of the Cotton Belt, but was practically absent west of eastern Texas and Oklahoma. Evidence obtained during the survey indicated that this distribution depended on climatic conditions, although no simple correlation could be determined. Besides the geographical distribution itself, the evidence included observed variation in amount of anthracnose infection on seedlings and bolls corresponding to variation in weather between seasons, studies on the relative degree of infection of seedlings grown from contaminated seed at different locations with diverse conditions, determinations of comparative spore loads on seed originating in different sections, and studies of progressive infection of the cotton plant from seedling to maturity. It was found that summer spread was largely saprophytic, infection taking place in any part of the plant, mostly through injured or moribund tissue which becomes more abundant as the plants mature. Infection advances or remains latent according to circumstances; under favorable moisture conditions, rapid spread in rotting tissue provides potential inoculum for boll infection. Evidence indicated that lack of summer rainfall is one of the factors in absence of the fungus on bolls and seed from Western regions. 5 -- The survey clarified the role of other organisms as well as of Glomerella in the causation of seedling disease and boll rot, explained discrepancies with results from seed treatment in different areas, and gave a solid basis for further research on control.

The results with Glomerella were somewhat unexpected at the beginning of the investigation and demonstrate clearly the role of surveys in defining the exact problems that must be faced. Complete results have been reported elsewhere (17, 25, 39).

OBJECTIVES AND HISTORY OF THE SURVEY

"The principal objects of the Survey broadly stated are: first, to collect information on plant diseases in the United States covering such topics as prevalence, geographical distribution, severity, etc., and second, to make this information immediately available to all persons interested, especially to those concerned with disease control." This brief statement, quoted from the first number of the Plant Disease Reporter (Plant Disease Bulletin as it was called for the first few years, vol. 1., no. 1, Aug. 15, 1917), is still an accurate summary of the Survey's functions.

The Plant Disease Survey was established as a separate unit of the Bureau of Plant Industry in 1917, during the first world war. The accompanying chart (Figure 1) gives a graphic record of its history. The chart shows very well the influence of emergencies on the demand for survey services: first is the first war, then the high peak of the second world war when the Survey administered the Emergency Plant Disease Prevention Program, finally the effect of the 1946 tomato late blight epidemic is manifested in the Forecasting Project under the Research and Marketing Act.

HISTORY OF THE PLANT DISEASE SURVEY

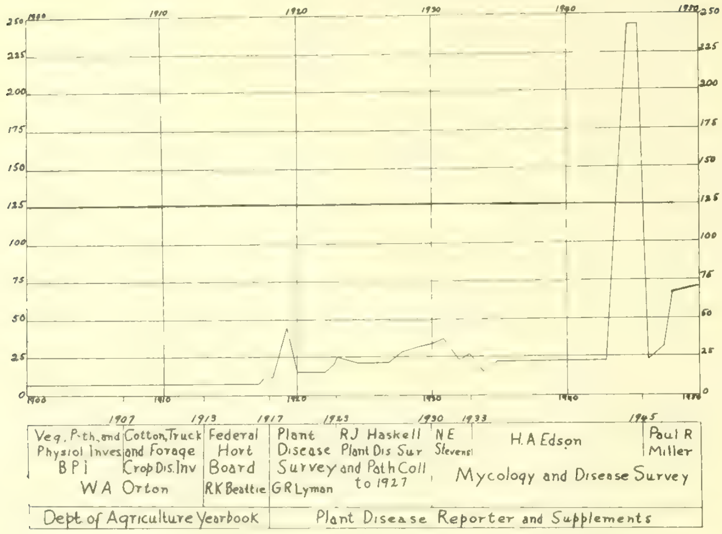

Figure 1. Chart indicating the personnel in charge, official source of publication, Divisional relation, and annual fluctuation in amount of appropriations of the Plant Disease Survey for the past half century. The line shows the amount of funds in thousands of dollars by increments of twenty-five.

A word about how the Survey operates will help in understanding the problems connected with maintaining the collection and recording of plant disease information. Figure 2 is a diagram of the Survey organization. Disregarding for the moment the broken lines, it is clear that the collaborators, who are State plant pathologists appointed to cooperate with the Survey in each State, form the mainstay of the reporting system. Except for brief periods or for special purposes, the Survey has always depended on voluntary reports. When the Survey was first established, practically all plant pathologists were personally and actively interested in its affairs, and the voluntary reporting system worked very well indeed. As time went on it became less productive, for various reasons cumulative in effect. The very increase in knowledge on occurrence, distribution, importance, etc., resulting largely from the Survey's own efforts, was responsible for a feeling that a saturation point had been reached, and that accumulation of further records would be useless. Pathologists' work became increasingly specialized and localized; correspondingly, interests became less comprehensive, chances of observation restricted, and time available for voluntary tasks scarcer. A series of drought years reduced occurrence of many plant diseases to a minimum, and although real understanding demands knowledge of absence or scarcity as well as of outbreaks, negative occurrence seems never to be very interesting. Outbreaks or emergencies of one kind or another arouse interest; ordinary occurrence or absence is apt to be slighted in reports. Finally, during the financial troubles of the 1930's, plant pathology in general felt the effects of the prevalent overproduction complex. Frequently it was said -- not by plant pathologists -- that plant diseases were useful rather than detrimental.

All of these factors, separately or together, influenced the effectiveness of the reporting system.

All voluntary systems have disadvantages, however, and we believe that the advantages have outweighed the drawbacks in the case of the Survey. At its best, the cooperative attitude of responsibility for the Survey has been a decided asset. I take this opportunity to acknowledge the Survey's indebtedness to its collaborators.

EARLY PHASE -- EVOLUTION OF SURVEY PROBLEMS: When the Survey was first established, under Dr. G. R. Lyman, distribution and importance of even some of the most common diseases was known only incompletely, and knowledge about plant disease occurrence in general was inadequate. One of the reasons for the Survey was the realization that this lack of knowledge about potentially important agricultural hazards might have serious consequences in war time.

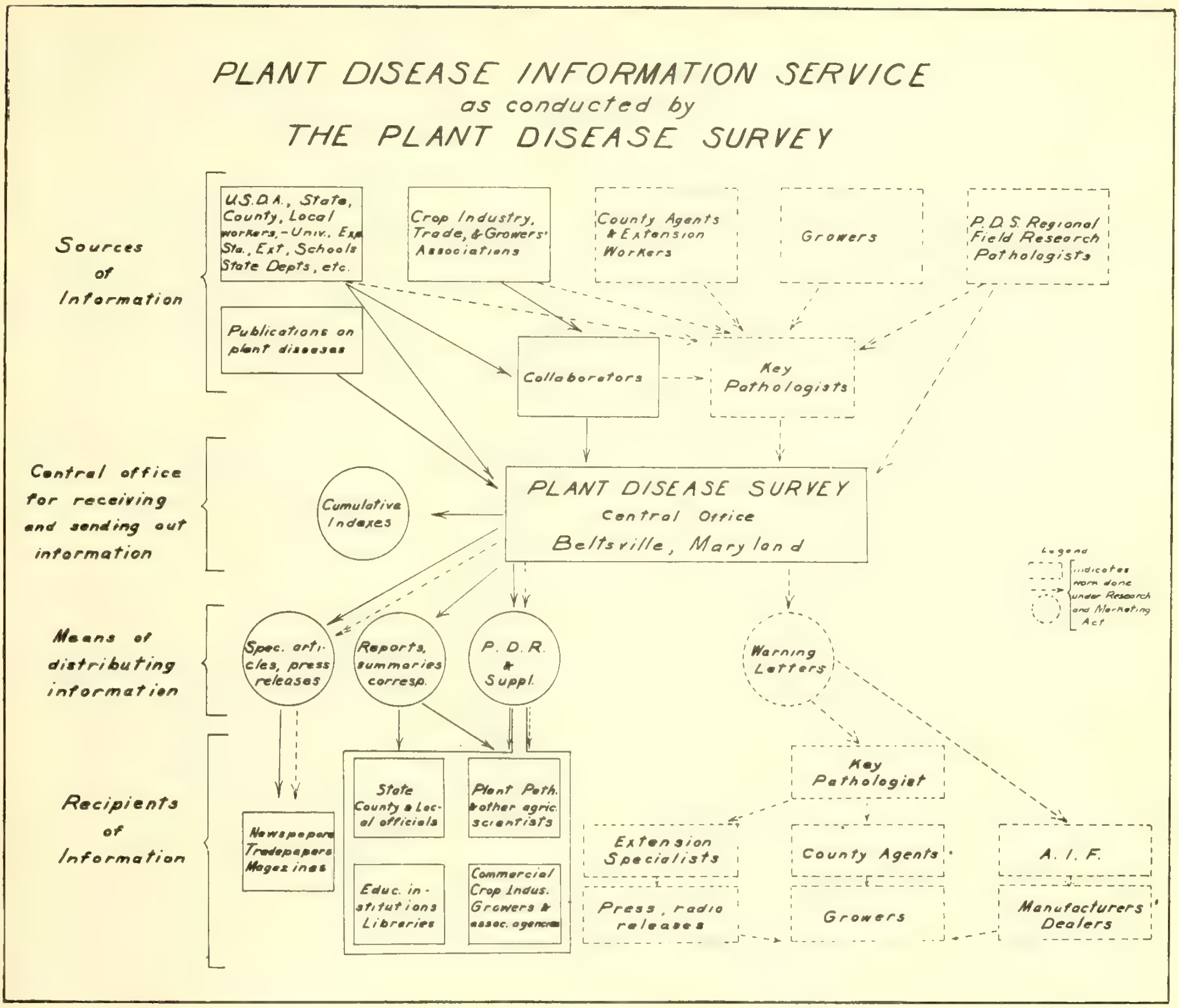

Figure 2

The Survey's first efforts were devoted to remedying this situation.

Regular frequent current reports on disease development on major crops were sent in during the season by the Survey's collaborators and published promptly in the Reporter. Annual summaries of all available information from whatever source were compiled each year.

The collaborators constituted a "watch-service" -- so designated by Dr. Lyman -- to watch for and report immediately new diseases or other unusual or threatening occurrences.

Special surveys were made to find out definitely where certain important diseases occurred. For example, the potato wart disease (Synchytrium endobioticum) was newly discovered in this country; its existence here was a menace but just how widespread it had become was unknown. In cooperation with the Federal Horticultural Board, the Survey determined the very limited distribution of this disease so that intelligently planned measures could be taken against its further dissemination. The early volumes of the Reporter contain progress reports on many such surveys, some conducted by the Survey itself, some under other auspices, e.g., the 1919 cereal disease survey conducted by the Office of Cereal Investigations.

In this period also the annual Crop Loss Estimates were started. The reason was obvious: to obtain some adequate idea as to the intrinsic and relative importance of the diseases of major crops, so that plant pathologists would be able to direct their energies effectively and have a measure by which to judge the results of their work. So little was known about the real extent of damage from plant diseases that any attempt to state it in understandable terms necessarily involved investigation of this specific problem, and the estimates were both a result of need for such study and a starting point for further work. However, it became evident with time that many circumstances prevented the estimates from being or becoming as accurate in the strict sense as it was thought numerical expression should be, and certainly that they were far from

being reliable enough for many of the uses to which they were put. Lack of knowledge about the connection between amount of disease and extent of damage was one factor; it could be corrected with study but in the meantime estimates were on an uncertain basis. Psychological bias has been discussed (18); conscious effort and objective criteria are needed to overcome it. Not the least factor was the changing situation already mentioned, in collaborators' interests and opportunities. In any event, the estimates, in this form, very likely had reached the point of diminishing returns before they were discontinued in 1939.

In justice to the estimates, however, we should say that some of them for which independent sources of comparison were available agreed in all essential features (35).

From the beginning until 1939 annual summaries on the incidence of plant diseases in the United States were compiled from the reports of Survey collaborators and other available sources. The usefulness of these summaries was generally acknowledged and the Survey gave them up with reluctance; reasons for their discontinuance are obvious from what has already been said.

The Crop Loss Estimates and the Annual Summaries are now source books for the history of plant diseases and of plant pathology in this country, for the period that they cover.

Toward the latter part of this early phase the Survey conducted comprehensive field studies in cooperation with selected States (2, 3, 4). A staff member devoted full time to identifying the diseases occurring on the crops grown in the State, determining their distribution and estimating the amount of loss they caused, as well as placing specimens of each in the Mycological Collections of the Bureau.

In view of the recent stress on the forecasting of plant diseases, especially late blight, not the least interesting although apparently forgotten activity of this early period is the watch service in Michigan, Wisconsin, and Minnesota reported in the following quotation (from Plant Disease Reporter (Bulletin) Vol. 2, No. 4, page 54, June 15, 1918):

"Conditions in the three States mentioned make the late blight problem a different one from that in the eastern and northeastern part of the country. Here outbreaks of Phytophthora are of less frequency than in the latter sections, but when an outbreak does occur the damage is enormous. For this reason spraying as a yearly proposition is not profitable. It is believed therefore that the best solution of the problem is to maintain an efficient watch service for the first occurrence of the disease."

Thus the logical connection of the Survey with plant disease forecasting was foreshadowed in the earliest times of its existence.

This early part of Survey history accumulated a much more satisfactory knowledge about the plant diseases that were present, where they occurred, how much damage they caused, how rapidly they spread, and, as far as could be determined or indicated from observation, the factors involved in spread and severity.

Although phases are clearly discernible in Survey history, there is no definite dividing point between them. The problems of one phase may carry over and endure for a while in the next and is a change in orientation that distinguishes each phase from its predecessor.

The dictionary definition of "survey", as far as it is pertinent to our Survey, is "1. to take a general or comprehensive view of. 2. to view in detail . . ." (American College Dictionary, Random House, 1947). In this early phase stress was on the general, or "comprehensive" view. This view continues throughout Survey history, but circumstances determine its prominence.

Even during this early phase, however, attitudes started shifting so that the second half of our Survey definition, the "detailed" view, became more and more the dominant one. With the background knowledge established, the need was greater for definite information on particular aspects. One response to this need was the surveys to determine the plant disease content of limited areas, as in various States. With the tobacco disease survey the change became marked enough to lead into a new phase just before Dr. R. J. Haskell left the Survey to become Extension Plant Pathologist for the U. S. Department of Agriculture.

Because of Dr. Haskell's strong belief in the value of detailed and systematic research and his ability to stimulate active cooperation on the part of the Survey collaborators the annual summaries and crop loss estimates reached their maximum completeness during this period.

SECOND PHASE -- FOCUSING: The concentration of Survey effort that had already become more and more evident in preceding years is the dominant characteristic of this phase. Two pressures determined its work: one was the demand for specific information, the other was the preeminence of economics in the thought of the time. At the beginning of this period Dr. Neil E. Stevens was in charge of the Survey. Characteristically, he understood how the possibilities of Survey investigation could best serve the current necessities.

The market disease survey already reported combined both economic viewpoint and specific inquiry (14). Another contribution to plant disease economics was the compilation of "plant disease hazards" also cited above (32), which called attention to the importance of plant diseases in

agricultural industries, and gave unmistakable proof that plant pathologists should be consulted, along with other agricultural scientists, in agricultural planning, land utilization programs, and irrigation developments, so strongly emphasized at that time.

The intimate connection between Survey and forecasting was demonstrated again. The records on bacterial wilt of sweet corn (Pseudomonas stewarti) showed that occurrence fluctuated with temperatures of the preceding winter, and a simple but precise method of forecasting severity was worked out, depending on the sums of the average temperatures for the winter months. The method has been so reliable that with some modifications it is still in use wherever sweet corn is important and the disease is a factor (33, 34). A basis for predicting occurrence of tobacco blue mold (Peronospora tabacina) also resulted from the study of Survey records, which indicated that earliness of appearance, rapidity of spread, and potential severity were correlated with January temperatures in South Atlantic Coast States. Later warning service experience has confirmed the accuracy of this observation (15, 23).

Some other accomplishments of this period may be mentioned briefly. Surveys that delimited the distribution of the rust diseases (Gymnosporangium spp.) of apple explained some hitherto puzzling circumstances about their occurrence (12, 13, 16). Crop surveys gave background for research on and control of diseases of tobacco, sweetpotatoes, and peanuts; these were reported currently in the Plant Disease Reporter between 1933 and 1936. The cotton seedling disease and boll rot survey described in detail above (25) was cut short by the Second World War, which opened another phase of Survey work.

THIRD PHASE -- WORLD WAR II AND THE EMERGENCY PLANT DISEASE PREVENTION PROGRAM: The third phase was again an emergency period. The safety of crops was a prime consideration in national defense and the Emergency Plant Disease Prevention Program was set up to ensure it. A certain amount of misunderstanding and prejudice that the program had to cope with at first was overcome as its real purpose gradually became evident, although never explicitly stated. The primary objective was to prevent malicious damage by enemy action, which required secrecy and a staff devoted to the one end and large enough to accomplish it.

A project of such magnitude as this, with its inherent problems of acquiring an adequate staff so suddenly and of operating with no idea of the duration of the work, and especially its confidential nature, was exceedingly difficult to administer. Its successful prosecution should be attributed in large measure to Dr. H. A. Edson, who possesssed the combined advantages of his own unusual administrative ability and his long years of experience with personnel and Civil Service affairs.

Achievements of the fundamental defense task have never been divulged. Published results (19, 27) of the Program's activity were a by-product, nevertheless, they were of the greatest aid to agriculture during the War period and later. They showed that the ever-changing nature of plant disease occurrence soon makes our information out-of-date or even misleading without constant and widespread watchfulness. On the positive side they demonstrated conclusively how much help planned surveys by a competent professional staff do give to investigation of plant diseases. This was the only time that the Survey has had the advantage of a really adequate field staff.

Certain activities of the Emergency Plant Disease Prevention Program were among the direct forerunners of the Crop Plant Disease Forecasting Project and thus led into the present phase of Survey history. One was the "warning service" rendered by the Emergency Program reports on the appearance and progress of potato late blight during the unprecedented epidemic in Southern States in the 1943-44 season. Similarly, the outbreak of the aster yellows virus disease in carrot fields of the Texas Winter Garden region was watched carefully. A related service was the locating and reporting of incipient disease outbreaks to make sure that scarce chemical control materials reached the places where they were needed in time to do some good, as far as was possible during the war (27).

The fundamental result of the Emergency Plant Disease Prevention Program, of great importance to the Survey, and also, we believe, to plant pathological study in general, was to establish the fact that survey data are not an incidental feature of plant disease investigation, but constitute one of the essential parts, and should be planned for as carefully as experimental work.

NOW -- SERVICE PLUS RESEARCH: Although many strictly Survey problems are of research rank, original investigation by the Survey has hitherto been restricted in extent and scattered in subject. The essential characteristic of the present phase is the acknowledgment of the necessity for research by the Survey in the performance of its own tasks. This is shown in the research provisions of the Crop Plant Disease Forecasting Project set up originally in 1948 under the Research and Marketing Act (31).

The second distinguishing feature is the establishment of regional forecasting as an official function of the Survey. It had long been evident that wide-scale watchfulness was necessary for

best control of certain diseases. While it is probably true that this knowledge would have led to an organized warning service sooner or later anyway, the tomato late blight epidemic of 1946 was such an emphatic demonstration that it crystallized demand for immediate establishment of a forecasting program. Moreover, plant pathologists recognized that merely a reporting service by itself would not be adequate for any but superficial results, and that research on epidemiology must accompany it; also, that both warning service and research should be on a regional scale.

Forerunners of the Forecasting Project may be enumerated briefly: the potato late blight warning service conducted by the Mississippi Valley Plant Pathologists' Committee during the war (11), the informal systems of current reporting on cucurbit downy mildew in the Atlantic Coast States (29) and on tobacco blue mold, the service of the Emergency Plant Disease Prevention Program in watching for appearance and development of plant diseases and reporting urgent need for fungicides, finally, the 1947 tomato late blight warning service.

This preliminary warning service in 1947 was the immediate response to the demand arising out the 1946 tomato late blight epidemic (26, 28). It was simply a warning service: the Survey received current reports on occurrence and accompanying circumstances from key pathologists in cooperating States and Canadian Provinces, assembled them into "warning letters", and relayed them promptly to the key pathologists, who in turn used them as basis for recommending the precautions that farmers should take against the disease. The practicality of this preliminary service was the decisive factor in the authorization of its successor, the Forecasting Project.

The present warning service operates in the same manner. Besides late blight (Phytophthora infestans) on both potato and tomato, it includes tobacco blue mold (Peronospora tabacina), and cucurbit downy mildew (Pseudoperonospora cubensis) (31).

The relation of the warning service to the Survey proper is shown in Figure 2, in which the broken lines represent the warning service, the solid lines the Survey. It is evident that both are dependent on the same type of cooperative reporting system.

Weather is so important in the development of these diseases that much study has been given to the usefulness of long-range weather forecasts, including those of private services and of the Weather Bureau. The 30-day forecasts of the latter have only recently become available; by arrangement with the Weather Bureau they are being sent to all key pathologists, who report, for the most part, that these forecasts increase the accuracy of their own disease predictions. This cooperation between Weather Bureau and warning service is the subject of Figure 3, adapted by the Weather Bureau itself for use on one of its daily weather maps (38).

Availability of fungicides and control equipment is another factor in control, and manufacturers of both are kept informed through their industry associations (Figure 2, 3). The annual summaries of the warning service give much attention to the success and extent of use of control measures; this analysis helps fungicide manufacturers to judge the efficiency of their own products.

The operation and basic features of the Forecasting Project's research program have been described elsewhere (31). At present it is concerned primarily with the epidemiology of late blight. Research topics include the separate and combined effects of meteorological factors, including microclimate; the existence, distribution, and characteristics of host and/or geographical strains of the organism; possibility, methods and routes of long-distance spread. In connection with this last phase a project involving the utilization of radioactive isotopes has been initiated. Preliminary reports on various aspects of this reaearch have been published (9, 10, 30, 36, 37).

In a way, except for its proved practicality, the warning service also is experimental, as far as criteria for basing predictions are concerned. Already, on the basis of existing knowledge, experience has increased the accuracy of the local forecasts. For the future, results from the research program, even though tentative and preliminary, will be applied to warning service use as soon as their usefulness for prediction is indicated. The accumulated records compiled in the warning letters and analyzed in the yearly summaries (22, 24, 28) will give invaluable background for interpretation and adjustment. These records, we consider, form a part of our research data obtainable in no other manner, and represent the equivalent of a region-wide laboratory experiment.

WHAT NEXT?

Development in the warning service indicates the definite likelihood of forecasting probability of disease occurrence for widespread regions, much as the Weather Bureau forecasts weather, instead of on a State or local basis, as now.

A more distant possibility closely connected with Survey objectives, perhaps not realizable in the near future but foreshadowed by pressure from increasing need, is research into methods of sampling and loss appraisal, leading toward a revival of loss estimates on a substantial basis

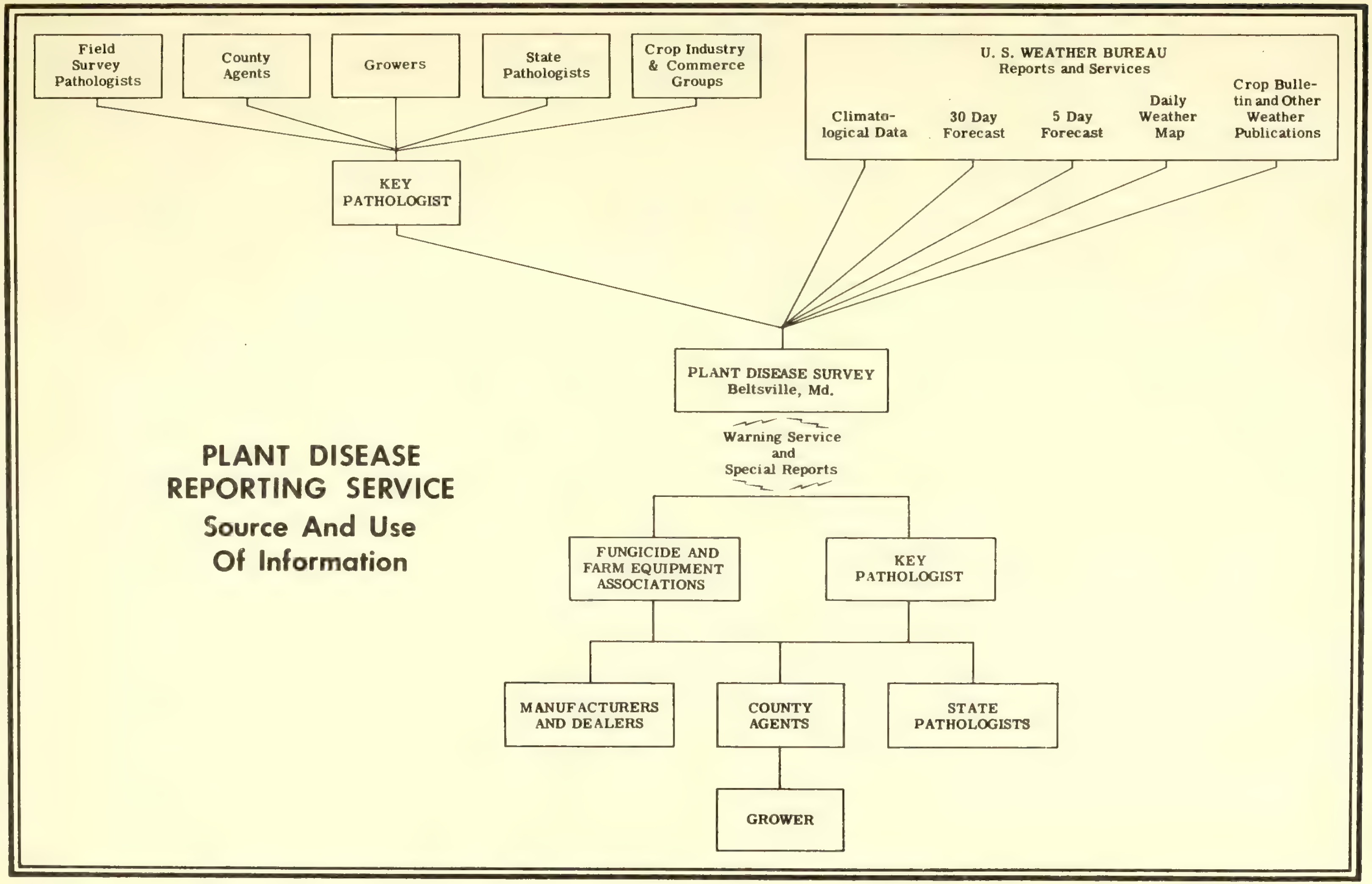
Field Survey Pathologists
County Agents
Growers
State Pathologists
Crop Industry & Commerce Groups
U. S. WEATHER BUREAU Reports and Services
Climato-logical Data
30 Day Forecast
5 Day Forecast
Daily Weather Map
Crop Bulle-tin and Other Weather Publications
KEY PATHOLOGIST
PLANT DISEASE SURVEY Beltsville, Md.
Warning Service and Special Reports
PLANT DISEASE REPORTING SERVICE
Source And Use Of Information
FUNGICIDE AND FARM EQUIPMENT ASSOCIATIONS
KEY PATHOLOGIST
MANUFACTURERS AND DEALERS
COUNTY AGENTS
STATE PATHOLOGISTS
GROWER

Figure 3

of experiment and observation.

Plant disease geography has so far received only limited attention from plant pathologists. We believe that there is sufficient foundation now for at least preliminary studies on this subject. The organization of plant disease knowledge that such studies would involve would certainly help to interpret much that is obscure or apparently contradictory in its present state. This is an important field of plant pathology, but of course it is one that requires cooperative effort.

These are not isolated, independent topics, since both loss appraisal and an adequately based science of plant disease geography will ultimately become necessary for progress in forecasting. Loss appraisal is also an adjunct to plant disease geography.

Both loss appraisal and forecasting are methods of testing our knowledge. Much as we may desire to have them absolutely reliable, there are times when immediate need calls for whatever guess can be formulated on tentative or incomplete information and to wait for accuracy would be worse than useless. Perhaps some such course as that outlined by Bode et al (6) should be included in the education of plant pathologists. I quote:

"Somewhere in the curriculum, . . . there should be a course in judging guessing, and the scientific method. This course is needed not only by the generalist, but by many other scientists. We have no way now to encourage or require a man to bring his education and intelligence to bear on estimation and prediction problems for which he has inadequate information. As a result, scientists often become stuffy and narrow in their views. To meet this need, we propose a course in educated, intelligent guessing. It would be principally a laboratory course, in which essentially impossible problems were put to the student, who would be required to supply answers and estimates of their trustworthiness, on the basis of the inadequate data given plus what he knows about the world. . . . . The main difficulty with this course would be finding an instructor equipped to teach it."

CONCLUSION

Elsewhere (20) I have said that the objectives of the Survey could be summed up thus: "to help plant pathologists make use of past experience with plant diseases, keep track of present problems, and anticipate future needs." This has been the aim of all Survey work, in all its aspects, throughout its history.

No acknowledgment could do justice to the planning that Dr. Lyman put into the Survey at the outset, which included all the functions that are logically a part of Survey work, nor to Dr. Haskell's genius for organization and cooperation that made the Survey's first phase so fruitful, nor to Dr. Stevens' original thinking that discovered such possibilities for Survey aid both during his tenure as head of the Survey, and afterward, nor the superior administration of Dr. Edson in spite of the difficulties faced, first in a time of "recession", and again in sudden expansion. The Survey is the result of their combined guidance.

I have already mentioned the role of our collaborators.

This discussion has stressed the "give-and-take" nature of Survey work. We hope for continued and increased cooperation from all plant pathologists.

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STATE QUARANTINES ON INTERSTATE MOVEMENT

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INTRODUCTION

It is generally recognized that the objectives of State quarantine and regulatory activities do not differ materially from those in the Federal field. Pest species are the same for both; there is the same need for knowledge on life histories, behavior, methods of spread, and means of control; for each there must be research, survey, community effort, popular understanding, proper equipment, financial backing, and legislative support. Both agencies may at times aim to eradicate pests, or to control them, or prevent their spread to new areas. In many cases State and Federal interests are practically identical and a common cooperative plan of attack can be set up against a specific pest. Thus any difference between the two agencies in their quarantine work lies not so much in objectives and operational conditions as in the legal powers each has available, the manpower and equipment each is able to muster, and the practical limitations within which each must work.

The matter of respective legal powers deserves come elucidation. Based on Constitutional grants of power Federal authority is paramount in the field of interstate and foreign commerce but is limited to these fields. This would imply that where the Federal government has exercised its constitutional right to prohibit or regulate the movement of specified materials or products in interstate or foreign commerce as a measure of pest protection, any attempt by a State to promulgate prohibitions or set up regulations on such movement in either field would probably be declared unconstitutional by the courts. However, the State's retained powers are regarded as unimpaired by this separation of function. State legal authority derives from powers inherent in the original status of the State as a sovereign political entity; all such original powers not relinquished to the Federal Union by the Constitution are still retained by the State. These retained powers include the police power, the right of entry and inspection, control over storage or maintenance, and the destruction of property when necessary in the public interest. When these potential powers have been given reality by specific State legislative action they come into practical effect and are enforceable in the courts. It is evident that the State thus stands on a far broader legal basis than the Federal authority in the scope of its quarantine functions. For this reason a State is in a position to undertake many projects for which Federal legal power is lacking or is too limited. For this reason also most large-scale quarantine enterprises require a judicious combination of Federal and State action to deal effectively with all phases of a complex situation. Cooperation of this kind is a commonplace feature in the quarantine field. In such cases the Federal authority is used to regulate or control interstate movements of dangerous materials, and State authority takes care of similar movements within the State. In addition, however, field surveys, inspection on premises, treatments at source, holding requirements, the destruction of property, and all other phases of the common program not involving movement in interstate commerce must be carried out under State legal authority.

This sharply drawn line between Federal and State legal responsibilities and limitations might introduce an awkward and embarrassing cleavage in function. These are two features, however, which go far to overcome these hard-and-fast legal distinctions and thus permit a high degree of flexibility in actual practice. The first of these is a widely prevalent legal provision for State-Federal cooperation, whereby either party may assist the other in various ways without disturbing or weakening the legal relations on either side. For example, Federal personnel may report violations of State quarantines; State inspectors may be empowered to act as Federal agents and vice versa; loans or contributions of equipment and materials can be made back and forth; facilities and services of various kinds can be interchanged; and purse strings may be loosened at times to help out the other cooperator. [1] In these and other similar ways a common program can be carried out successfully despite the seemingly inflexible legal limitations mentioned above.

A second factor in the situation permits considerable freedom of State quarantine action in spite of the apparent legal limitations arising out of Constitutional division of powers between the Federal authority and the State. This is the right to impose interstate quarantines. Basically this function belongs to the Federal agency because of its Constitutional responsibilities in interstate commerce. Yet there are many pest situations which for technical, operational, financial, or administrative reasons can be met more adequately by State quarantine and regulatory measures than by Federal action. Consider, for example, the nursery inspection program established in

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[1] S. R. A. (Service & Regulatory Announcement), Fed. Hort. Bd., 1926; p. 62.

practically every State. Individual nurseries in varying degrees normally distribute their products both within the State and to other States. While the Federal agency could properly undertake to regulate the interstate phase of such movement, the intrastate portion of it is outside Federal jurisdiction. Nor for very practical reasons could a system of dual inspection be instituted so as to examine separately nursery stock going to other States and that to be distributed within the State; at the time inspection must be done no one can segregate the nursery plants into these two categories, nor even forecast the proportions of any lot which will eventually reach these two distribution channels. The actual inspection procedure must therefore be carried out without reference to eventual outlets, and the sensible course is to leave both phases in the hands of the State.

In this illustrative case, as well as widely elsewhere, the Federal government has refrained from exercising to the full its right to control interstate commerce and has preferred to rely to a large degree on State quarantine action, usually well supported where needed by the Federal cooperation above mentioned.

Federal withdrawal in this way from its own proper field is, of course, legally sanctioned. Following the Supreme Court decision of 1926[2] which strongly favored Federal assumption of its responsibilities in matters of interstate pest spread, the numerous practical difficulties to be met in adopting an extreme policy in this field became apparent, and Congress by joint resolution in 1926 clarified the Federal-State relation by ruling in effect[3] that until the Federal authority has acted in a given pest situation in interstate commerce the State may take such protective action as it deems necessary. This dictum established the right of the several States to control and regulate incoming plant materials for pest reasons, when no Federal measures were in effect on the particular subject in question. This resolution has since served as a sound basis for the validity of the various State quarantines of interstate nature covered in this review.

State quarantine and regulatory activities fall rather naturally into two categories: those that attempt to prevent the entrance of crop pests into the State from areas outside its borders; and second, those designed to suppress, control, or prevent the spread of pests within the State's own territory. The latter group includes in turn both the specific quarantine measures relating to individual pests or well-marked problems affecting the State's internal welfare, and also those activities of general or service nature carried out under authority of the State's legal powers, such as nursery inspection, seed potato certification, and the like.

It may be remarked in passing that the service element in many of these intrastate activities may be present to such an extent that it quite overshadows the accompanying exercise of legal powers. In fact the quarantine and regulatory field shades off at times into situations where legal powers are not invoked and the problem is handled on the basis of a technical service assistance to private enterprise. Seed potato certification and field or vegetable seed certification furnish examples representative of both regulatory and nonregulatory types.

The present review attempts to deal only with those activities concerned in interstate relations, leaving for separate consideration those exercises of State power which are primarily intrastate in character.

The plant pathologist will readily recognize a number of factors favorable to the success of State quarantines which are intended to prevent or delay pest spread into the State from outside areas. In calling attention to the chief of these factors it is understood that an obverse relation would be more or less unfavorable to quarantine success.

It is obvious that a pathogen with a highly restricted host range, or one requiring an alternate host, or one low in propagation rate, or tied to the soil, or perishing quickly, is a less troublesome quarantine adversary than a pest species attacking numerous hosts, which produces enormous populations, is wind-borne, and has unusual longevity.

Again a quarantine has greater chances of success in cases where spread is largely dependent on the movement of carrier materials normally few in number, and traveling in well-marked channels easy to keep under surveillance.

The existence of effective control or treatment procedures is an important factor in quarantine prospects. A reliable treatment for hazardous pest carriers strengthens the quarantine position materially. So do rotation practices, resistant hosts, spraying methods, and similar control possibilities. In fact treatment and control may at times develop to a stage where resort to quarantine is judged to be unnecessary.

Another factor of prime importance lies in the effectiveness of survey and inspection methods. A quarantine is greatly weakened by having to depend on vague and unsatisfactory survey procedure or on unreliable inspection results.

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[2]S.R.A., Fed. Hort. Bd., 1926; p. 61.
[3]S.R.A., Fed. Hort. Bd., 1926; p. 62.

The volume and nature of movements also affect quarantines. It is difficult to regulate successfully a high volume movement involving varied types of commodities, especially where these represent great economic values, are in urgent demand, and may use a number of transportation channels.

The nature and extent of pest damage are also to be considered. Obvious and spectacular host destruction may arouse an earnest quarantine support, not always realized where the pest is of insidious or persistent type and the damage is less readily grasped and evaluated.

Finally, there is the matter of popular support. In a last analysis public approval and compliance are vital to the success of any large-scale quarantine undertaking. Whatever success may be obtained by an initial burst of administrative energy, results in the long run cannot exceed the level of public confidence and acceptance accorded to the measure.

Generally speaking, State quarantines can rely only occasionally on the automatic protection afforded by mountains, seas, plains, deserts, and other natural features. Climatic differences are usually too small to be significant. And a well-developed road network often permits endless truck and auto traffic beyond the control of any practical State supervision effort. Because of these limitations and handicaps State quarantines can only succeed in exceptional circumstances in permanently excluding an undesirable pest. In the main their greatest value lies in delaying the advent of pests so as to permit gradual adjustment, or the working out in advance of effective control measures.

When the field of plant diseases is examined in the light of these factors, some favorable and some unfavorable to quarantine action, it is evident that the situations where quarantine action is likely to be profitable are not so numerous as one might think. Excluding the biologically hopeless cases, those too costly to be undertaken, those well enough taken care of at-source, and those in which successful control methods largely obviate the need for regulatory action, the disease problems in which prevention of spread would be accomplished by quarantine methods are greatly lessened. Among these few, however, will be found cases where the primary object is to keep individual lots of planting stock free from some objectionable pest already widely distributed, or to protect long-term plantings, such as orchards, from early pest introduction, or to avoid local establishment of a pernicious parasite. Quarantine action may be justifiable for these specific purposes, as well as for preventing large-scale areal spread.

QUARANTINES AT-SOURCE

State quarantines designed to prevent the interstate spread of pests may adopt two distinct patterns. In the most simple and direct type the State authority attempts to prohibit or regulate the incoming movement of pest-carrying materials from infected areas in another State or States. In the second type the State where the pest occurs sets up a system of quarantine control and safeguards, effective for its own internal needs, and at the same time serving to prevent dissemination of the pest to other States; it is assumed that these outlying States will accept this arrangement as adequate for their protection. For convenience these two types may be designated as "destination" quarantines and "source" quarantines.

The idea of preventing spread at-source is biologically sound. It has wide practical acceptance in such matters as nursery stock inspection, seed potato certification, and the like; and it has been frequently adopted in individual quarantine situations since the early days. The economy of effort in this scheme is obvious, since effective action at source may obviate the need for numerous individual quarantines by the many States nedeing protection. Further, this method avoids certain enforcement weaknesses likely to diminish the value of destination-State quarantine action, especially where the volume of movement is large and traffic channels are so many and varied that surveillance becomes difficult and costly. Finally, the source-State quarantine fits more easily into normal commercial practices and thus causes less disruption and irregularity in commodity flow.

While it is thus evident that the quarantine at-source represents a higher plane of quarantine organization and efficiency than the destination-State type, the former must depend very heavily on mutual confidence among State officials for its success. In entrusting his State's welfare to the good faith and competency of officials in another State an administrator to some extent gives over into other hands his own special responsibility for his State's protection. The advantages from this step may justify its adoption in many cases, but it is quite understandable that a responsible official would be reluctant to agree to this plan where the protection offered his State did not seem adequate, or where a particularly destructive pest was concerned, or where a vital industry in his State was threatened. In these more serious situations an administrator could scarcely be blamed for falling back on the direct destination-State type of quarantine action,

which with all its defects retains protection measures in the State's own hands.

An important element in these prominent situations, from the point of view of acceptance of the quarantine at-source plan, is the extent to which Federal interest and cooperation enter into the picture. Where a deep and active Federal concern is present, State acquiescence in the common program is likely to be materially strengthened.

STATE TERMINAL INSPECTION

The terminal inspection of nursery stock is an outstanding element in the quarantine organization of several States. While the State by virtue of its retained original State powers has all the legal authority needed to conduct inspection in connection with public carriers such as ships, trucks, railroads, and airplanes, as well as autos and other private vehicles, a problem arose early in quarantine development in connection with parcel post shipments of nursery stock and other plant products carried interstate in the United States mail. The State's inspection power could be exercised on such parcel post shipments only after delivery to the addressee, a procedure obviously impractical from the administrative standpoint. To relieve this situation legislation in 1915[4] enabled the U. S. Postal Service to set up an orderly procedure for State inspection before delivery of all packages containing specified kinds of nursery stock, and to require for such packages an external statement of contents, as well as a nursery stock certificate issued by a State or Federal inspector.[5] The plan further provided that a State desiring to undertake this inspection should submit a list of the types or classes of nursery stock for which predelivery examination was needed, as well as the pests concerned, and that this list should be approved to the Post Office Department by the Secretary of Agriculture. Under this arrangement the States specify the inspection places to which parcels are to be routed and there made available for the State inspector's examination.

In this scheme the State's inherent right to inspect materials entering its borders was recognized, and participation in the plan represented a definite Federal cooperative relation with each State concerned. It was understood that, although this provision for terminal inspection included the right of the State to refuse entry, or to treat, or otherwise safely dispose of materials found to be infested with injurious pests, it did not originally contemplate Federal responsibility for the enforcement of State regulatory restrictions or requirements imposed on interstate movement. The arrangement permitted inspection and the safe disposition of the specified products if infested, but nothing more.

However, this cooperative relation was broadened in 1936 by an amendment to the Postal Laws and Regulations[6] which charged the postal service with the duty of aiding States in the enforcement of State quarantines and regulations pertaining to injurious pests. After these State quarantine measures had been formally approved by the already established procedure, the Postal Service agreed to withhold delivery of and submit for State disposition parcels moving interstate in violation of the prohibitions or regulations imposed thereby.

At the present time[7] 11 States, Hawaii, the District of Columbia, and Puerto Rico maintain the terminal inspection procedure. Four States have discontinued this feature--Georgia (1933), Louisiana (1945), Oklahoma (1944), and Wyoming (1933).[8]

SCOPE AND LIMITATIONS OF THIS REVIEW

A summary of State and Territorial quarantine and regulatory measures was prepared by the Division of Domestic Plant Quarantines in 1930[9] and is being kept current by revision in mimeographed form as a separate B.E.P.Q. 578 for each State, Territory, and the District of Columbia. This publication gives a digest of the specific quarantines, rules, and regulations of the various States and Territories and the District of Columbia, and also covers their requirements for interstate movement of nursery stock into them from other States. The present review therefore does not attempt to list these measures by States but proposes instead to treat them from the host and pathogen standpoint, an approach more acceptable perhaps to the plant pathologist.

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[4] S. R. A. Fed. Hort. Bd., 1915; p. 20; Terminal Inspection Act of March 4, 1915.

[5] S. R. A. Fed. Hort. Bd., 1926; p. 24.

[6] S. R. A., B.E.P.Q. 1936, p. 180. Post Office Order No. 9620, October 15, 1936.

[7] B. E. P. Q. 578; Summary of State nursery stock shipping requirements and plant quarantines and regulations affecting interstate shipments. 1949 (Mimeographed).

[8] S. R. A., B. E. P. Q. 1941; Cumulative Index 1914-41, pp. 82-83.

[9] U. S. D. A. Miscellaneous Publication No. 80, Summary of State and Territorial Plant Quarantines Affecting Interstate Shipments. July 1930; Revised, March 1946.

In presenting these in detail, it is necessary to note that while these States make use of varied designations -- quarantine, order, rule, regulation, prohibition, restriction, requirement, and the like -- all of these terms represent some exercise of the State's legal authority for preventing pest dissemination.

The highly important item of nursery stock inspection is so well established and so universal and uniform that it may be disposed of with a few general comments. In the first place, as indicated above, nursery inspection follows the at-source pattern rather faithfully. Except for certain specific diseases, and for the terminal inspection arrangements elsewhere mentioned, it is customary for each State to rely on inspection in the State of origin, with the sanitary status of each shipment indicated by a certificate or permit of some sort. Although there are considerable variations in the concept of what constitutes "nursery stock" among the States, as well as differences in the inspection standards and procedures, enough uniformity exists to permit a liberal interstate exchange of planting materials.

A pathologist might complain that the nursery inspection system is heavily concerned with insect problems, and that its methods are much better adapted to entomological than to pathological needs. In justice it should be said that this situation may mean, on the one hand, that ordinarily inspection is easier for insects than for diseases, and that insect treatments are likewise more effective; and, on the other hand, that popular demand lays more stress on insects than on diseases. When pathologists have created an insistent demand for disease-free nursery stock and have provided means for making it so, this apparent unbalance will, no doubt, correct itself readily.

This review has aimed to include all State quarantine actions of interstate character. Although every effort is made to keep the Divisional information files complete and current, it is quite probable that a few of these quarantines have been overlooked or have not yet come to our notice. For any omission of this sort apology is offered.

ALMOND VIRUS DISEASES -- See under Prunus Virus Diseases

APPLE RUST (Gymnosporangium juniperi-virginianae) -- The only State taking quarantine cognizance of this disease is New Mexico, which by law (Ch. 118, Sec. 4; 1937) prohibits entry into the State of eastern red cedar, Juniperus virginiana, to protect its apple orchards and its native cedar, J. scopulorum, from this rust.

APPLE SCAB (Venturia inaequalis) -- The Regulations issued under Utah law, No. 3, effective June 1C 1947, provide for inspection of all apples (fruits) entering the State on account of apple scab. This same regulation applies to pears on account of pear scab (Venturia pyrina).

Inspection of fruits for apple scab is generally regarded in other States as falling into market-grade procedure rather than as a measure to prevent scab dissemination.

APRICOT VIRUS DISEASES -- See under Prunus Virus Diseases

AZALEA FLOWER SPOT (Ovulinia azaleae) -- Three States (Oregon, Washington, and Texas) regulate the entry of azaleas from the South Atlantic and Gulf States on account of this disease, and Washington and Oregon include Rhododendron and Kalmia. Certificates are required by Oregon and Washington (Washington, Q. Order 28, Oct. 19, 1944; Oregon, Q. Order 47, July 1, 1943) to establish that the plants were grown in soil free from the pathogen and that surface soil was removed. Texas (Q. 129, Nov. 6, 1940) requires a spray or dip procedure, and absence of old leaves, flowers, and mulch.

In effect, these regulations are all merely special applications of the standard nursery stock inspection procedure.

BAMBOO DISEASES -- See under grass plants

BLUEBERRY STUNT (virus) -- Michigan (Quarantine No. 606; Sept. 1, 1944) is the only State to take action regulating the entry of blueberry plants and scion wood on account of this disease. Entry is conditional on freedom from this virus trouble as established by State-of-origin certificate.

BRAMBLE PLANTS DISEASES -- See under Rubus Diseases

BROMELIADS DISEASES -- See under Pineapple

BUTTERNUT BUNCHY DISEASE -- See under Walnut

CABBAGE PLANTS -- See under Seedling Vegetable Transplants

CHOKECHERRY X-DISEASE -- See under Prunus Virus Diseases, Peach X-Disease

CORN DISEASES -- See under Grass Plants

CRANBERRY FALSE BLOSSOM (Virus, Chlorogenus vaccinii) -- Since, according to Holmes, this virus probably originated in Wisconsin and was spread from there to other northern cranberry States, Wisconsin Order No. 6 (Jan. 1, 1928), requiring certificate of freedom from this trouble within a small tolerance for entering cranberry plants, must be regarded as a measure to

keep down infection in new plantings or to avoid introduction into clean cranberry bogs, rather than as a quarantine step with a broad geographic objective. Perhaps on account of the success of flooding and spraying to kill the leafhopper vector and some reported varietal resistance, resort to quarantine has not been considered necessary in other States.

CAMELLIA FLOWER BLIGHT (Sclerotinia camelliae) -- Seven southern States have set up quarantine restrictions on camellia to prevent introduction into their extensive and valuable camellia nursery and garden cultures of this flower blight fungus, apparently a relatively recent immigrant from Asia to the West Coast States. The almost uniform regulations for these States, apparently worked out by Southern Plant Board discussion, bar the movement into them from infected western sources of balled and potted camellia plants and camellia cut flowers, but allow entry of bare-rooted camellia plants with petals still unopened at the time of shipment and so certified at source. Four States (Alabama, Louisiana, Mississippi, and Tennessee) require affidavits from camellia shippers in States maintaining no restrictions against camellia flower blight that they have not received or will not receive restricted materials from the respectively designated infected areas.

Measures of this type have been promulgated by Alabama (Quarantine No. 4; Dec. 15, 1949); Florida (Rule 51; June 24, 1949); Georgia (Quarantine No. 9; July 1, 1949); Louisiana (a quarantine order of July 20, 1949); Mississippi (Rule 71; June 22, 1949); South Carolina (Quarantine Order of August 1, 1949); and Tennessee (Quarantine Notice No. 14; July 1, 1949).

While these actions aim to exclude the flower blight pathogen, their precautionary character is indicated by the fact that there could be no previous survey assurance of a general freedom of the areas in question from this flower blight. This situation illustrates a not unusual quarantine difficulty -- the necessity of taking quarantine action before there is adequate knowledge on pest distribution. It may be noted also that since air dissemination by conidia is lacking and infection must be effected by direct ascospore discharge from the wintered sclerotial stage, the prospects for reasonably effective local control tend to lessen the pressure on quarantine methods.

CHESTNUT BLIGHT (Endothia parasitica) -- The now practically complete infiltration of this destructive Asiatic fungus intruder into all the eastern range of the chestnut and chinquapin has for years provided a spectacular and extreme example of pest damage. Protected by a broad prairie and desert belt and lacking native chestnut forests, the Pacific Coast States and western Canada have had to contend with only a few scattered introductions of the disease, all of them now eradicated or in process of elimination. Because of increased interest in chestnut production in these States four of them have established quarantine barriers to prevent the entry of infective materials from eastern sources. All these measures by California (Quarantine Procl. No. 2; Jan. 19, 1935); Idaho (Quarantine Order No. 16; Apr. 29, 1939); Oregon (Quarantine Order No. 27; Feb. 5, 1937); and Washington (Quarantine Order No. 8; June 10, 1927) prohibit entry into the State of trees or plants, nuts, grafts, cuttings, and scions of chestnut or chinquapin from States east of and including Montana, Wyoming, Colorado, and New Mexico. California and Idaho had established earlier restrictions in 1927 and Oregon in 1935, which the measures cited have superseded.

The effectiveness of prohibitory action as compared with regulated entry, the natural protection afforded the West by the prairie and desert strip, and the highly developed interest of the Pacific Coast States in pest protection methods are all favorable to the success of these protective measures.

The State of Arkansas is the only other State with chestnut blight quarantine restrictions. This State (Rule 56; Dec. 11, 1937) regulates by a permit system the entry into it from outside sources of plants, plant parts, and seeds of chestnut and chinquapin.

CITRUS: VARIOUS DISEASES INCLUDING CITRUS CANKER (Xanthomonas citri) -- The citrus-growing States have imposed very stringent restrictions on citrus fruits, seeds, and nursery stock, partly on account of fruit flies, scales, and other insects, and partly on account of important diseases of these hosts, among which citrus canker is outstanding.

Five States having important citrus interests have established special regulations on the entry of citrus nursery stock (plants, cuttings, budwood, seeds). In the other Gulf and Southern States, and in Puerto Rico, citrus diseases are taken care of in conjunction with insect quarantines or as a part of the standard nursery stock inspection procedure.

Alabama (Nursery Regs.; revised; Sept. 24, 1943) allows entry of citrus nursery stock under a permit system. An official certificate from the State of origin must establish freedom for two years from citrus canker, scaly bark, and other important citrus diseases, both in the nursery production center and its environs; further , complete defoliation is required.

Arizona (Quar. Order No. 5, amended; 1948), likewise uses the permit system for nursery stock introductions, requires defoliation, and stipulates a three-year period of freedom from

citrus canker to be established by certification at origin. Citrus fruit must be so certified also.

California (Quar. Procl. No. 1, revised; Dec. 2, 1948) does not require a certificate from the State of origin for citrus nursery stock, fruit, or seeds, but depends on its own permit tags issued to the authorities of the State of origin to be used only on shipments from areas determined by California to be free from canker (and other serious citrus pests) for a three-year period. In the case of fruit, California calls for annual surveys in the production State to assure current freedom from canker and fruit fly pests.

Florida (Rule 28, revised; March 22, 1947) prohibits the entry of all domestic citrus nursery stock materials, including seeds and fruits, except for shipments by the U. S. Department of Agriculture, and for new citrus type stock for which a special permit is secured from the State Plant Board. This extreme action is taken on account of citrus canker, the quick decline of citrus, and other serious citrus diseases. There are also special restrictions placed by Florida (Rule 30, revised; March 22, 1947) on citrus fruits from Arizona and California on account of the brown rot of lemons and oranges (Phytophthora citrophthora).

Texas (Citrus Nurs. Stock Regs.; Feb. 4, 1946) allows the entry of citrus seeds from areas free from citrus canker or quick decline and so certified, and requires their disinfection with corrosive sublimate. In regard to citrus nursery stock, Texas follows the California plan of permit or license, based on the Texas official's knowledge of disease conditions at source, but requires also a State-of-origin certificate.

COCONUT BUD ROT (Phytophthora palmivora) -- To supplement its internal measures for the control of this disease, Puerto Rico has included in its plant pest Act (No. 35; May 11, 1934; amended May 14, 1948) a stipulation that coconut trees, nuts, or other raw coconut materials shall be certified at origin that the district of production is free from bud rot or other coconut disease or insect pest not widely prevalent in Puerto Rico. Here, as in several other situations noted, the action taken, although embodied in the organic pest act, must be regarded essentially as a special case in the nursery inspection field.

COFFEE DISEASES -- Puerto Rico (Quar. No. 4; July 30, 1948) aims to protect its coffee industry by generally prohibiting entry into the Island from other United States areas plants and seeds of coffee, except as may be authorized under a permit arrangement for experimental purposes. Roasted coffee beans and their ground products are excepted from this quarantine, which is mainly designed to avoid introduction of coffee rust, Hemileia vastatrix. This quarantine is complementary to Federal Foreign Quarantine No. 73, which protects the Island's important coffee cultures against pests and diseases from other countries.

Hawaii also maintains a quarantine on coffee (Reg. 1.3; Aug. 14, 1947), which brings under a permit procedure all coffee plants or plant parts or seeds for propagation purposes from elsewhere in the United States. The quarantine board may authorize limited entry for propagation purposes under conditions considered safe and when needed in the public interest.

COTTON DISEASES -- Three States and Puerto Rico have issued regulations relating to or including diseases of cotton. Nevada, in setting up a special cotton district in the State, requires by the terms of its seed law regulations (April 15, 1949) that seed cotton, unprocessed cottonseed, or unginned cotton shall enter such district from elsewhere in the State or from outside the State under a permit system, presumably to avoid introduction of (unspecified) plant diseases and other cotton pests. The primary intent of the regulations appears to be intrastate in character, and although its interstate feature is clear enough, this element represents almost the minimum of interstate quarantine regulation.

Arkansas is somewhat more specific in its seed law regulations where Rule 68 of August 22, 1939, provides that cottonseed for planting purposes shipped into the State shall bear a State-of-origin certificate establishing a reasonable freedom in the field where grown from anthracnose, wilt, and other serious communicable diseases.

Oklahoma (Quar. Order No. 4; Sept. 1, 1944) quarantines cottonseed from all out-of-State sources on account of anthracnose (Glomerella gossypii) and bacterial blight (Xanthomonas malvacearum). The permit system is used, and along with the customary shipment procedure treatment of the seed with Ceresan is a requirement.

The cottonseed and cottonseed products regulations of Puerto Rico are also of minimum nature. Its plant pest Act (No. 35; May 11, 1934) stresses the exclusion of cotton boll weevil but includes as reason for restrictions also "any other cotton pest or disease not widely prevalent in Puerto Rico." A certificate by the State of origin with power of inspection on arrival is the indicated procedure here.

EASTERN FILBERT BLIGHT (Cryptosporella anomala) -- The considerable filbert industry developed in recent years in the three Pacific States has long been apprehensive of the establishment there of the leaf blight fungus indigenous on the natural Corylus species of the East. Quaran-

tine measures promulgated by California (Quar. Order No. 4; Jan. 22, 1927), Oregon (Quar. Order No. 20 A; revised Feb. 5, 1937), and Washington (Quar. Order No. 6; June 10, 1927) aim to prevent the westward spread of this apparently destructive pathogen by excluding all trees, plants, cuttings, scions, or grafts of both cultivated and wild filberts originating in the infected area -- that is, the territory east of and including the States of Montana, Wyoming, Colorado, and New Mexico.

The uniformity of action taken by these States doubtless reflects the helpful results of a cooperative approach promoted by the Western Plant Board.

ELM DISEASES: DUTCH ELM DISEASE (Ceratostomella ulmi) AND PHLOEM NECROSIS VIRUS DISEASE -- The only State which has invoked quarantine methods to prevent the entry of these elm troubles is California (Quar. Procl. No. 21, July 19, 1947; amended June 5, 1948), which lists a wide group of States as infected from Arkansas and Colorado east, and prohibits entry into California from them of trees, plants, and all parts of these; elm logs or cordwood; and lumber and other materials or articles containing elm wood not free from bark. From uninfected States materials capable of carrying these diseases or its insect agents of transmission are required to bear certificates establishing freedom of their local sources from these diseases.

It will be observed that this quarantine has both prohibitory and regulatory features in a combination designed to secure the maximum protection to the State with a minimum of interference in normal movement of articles and materials.

GLADIOLUS CORM DISEASES -- Michigan (Reg. No. 611; May 13, 1947) has set up certification requirements for the production of gladiolus corms within the State, and has established tolerances for the several diseases of these corms. This certification procedure is intended to serve intrastate needs and at the same time give assurance of a standard product for shipments to other States. While this quarantine action is technically of purely intrastate character, it is apparently intended to serve as one of the several at-source measures proposed as a means of providing general interstate protection in the movement of gladiolus.

A similar measure by Kansas (Entomological Com. Rules and Regs. 7-1-32; June 10, 1948) provides for two field and one or more storage inspections, as well as a tolerance schedule for diseases present. It is indicated that gladiolus corms offered for sale in Kansas must meet an equivalent standard and be so certified.

Both these measures appear to have taken form out of the deliberations of the Central Plant Board on the subject. It is clear also that the procedure adopted represents a special case of the general nursery stock scheme, and that in its interstate relations the protection-at-source pattern is used.

GRAPE, PIERCE'S DISEASE (virus) -- Another special case of quarantine of nursery stock type is found in the Arizona Quarantine Order No. 17 (Reg. 1.1; Aug. 14, 1947), which requires that plants and propagative parts (except seeds) of grape will be accepted from California and Texas only when accompanied by a certificate establishing that the plants or cuttings in the shipment were obtained from a location where this virus disease is not known to exist within a radius of one mile. As in other cases of this type the scheme of protection at source as adopted.

GRASS PLANTS -- The typical State quarantine is of more or less specific nature, covering a single outstanding pest, or a single crop plant or a closely related group of hosts. The Territory of Hawaii (Reg. 1.1; Aug. 14, 1947) has departed somewhat from this model by issuing a quarantine on a variety of grass plants, on account of pests and diseases in general. While sugarcane looms importantly in this picture, there are also included bamboo, corn, sorghum, and other members of the Gramineae.

The use of a permit system allows the quarantine authority to exercise its best judgment on both the admissibility of certain propagating materials of the grass species concerned, and the conditions which would be required for their safe entry. This flexible type of procedure thus assures the maximum liberality in entry without sacrificing the important element of safety.

KALMIA, Ovulinia azaleae -- See under Azalea

NARCISSUS BULBS -- Three States which have developed an extensive production of narcissus bulbs aim to protect this industry from further introduction of certain eelworms, primarily the bulb nematode (Ditylenchus dipsaci Kühn). Since this nematode has long been widely distributed throughout the country, the quarantine objective is not to protect the State from a new and hitherto unknown pest, but to insure clean planting stock for gardens and propagation fields. Thus these quarantines fall naturally into the nursery stock category as special cases.

In all three States the protective scheme sets up inspection, treatment, and certification procedure for the State's own narcissus bulb production, and then requires a similar procedure for bulbs entering the State from elsewhere, compliance with such standard to be established by certification at the production source.

In Washington (Quar. Order No. 5; Sept. 10, 1946) and Oregon (Quar. Order No. 54; Dec. 10, 1946), as well as in North Carolina (Quar. No. 6, revised; Jan. 8, 1941), the standard hot water treatment is prescribed for infested bulbs.

Both Washington and Oregon provide also for the use of formaldehyde in connection with this treatment. North Carolina includes the narcissus bulb fly (Merodon equestris Fab.) as a reason for quarantine and where this pest alone is present prescribes a shorter hot water treatment or cyanide fumigation.

NECTARINE VIRUS DISEASES -- See under Prunus Virus Diseases

ONION PLANTS -- See under Seedling Vegetable Transplants

ORCHID PLANTS: VARIOUS PESTS AND DISEASES -- While orchid plants would seem to deserve no more quarantine attention than many other exotic ornamentals, such as the saxifrage group or cactus, the species of which are usually classed along with numerous others as of regular nursery stock type, yet the wide range of the orchid family, its horticultural popularity, and particularly the considerable economic values it often represents, justify special quarantine consideration under some circumstances. The Territory of Hawaii, because of its climatic advantages and interest in floral development has been outstanding in orchid culture, and has issued a quarantine (Reg. No. 1.5; Aug. 15, 1947) of the usual type, providing for the entry of these plants under permit so that they may come under orderly inspection and be freed from accompanying pests before being released into horticultural use. A certificate by the State of origin is required; a greater pest risk is recognized in orchids from tropical as compared with those from temperate regions; and a system of quarantine detention is set up for plants or shipments of doubtful status.

PEAR SCAB Venturia pyrina -- See under Apple Scab

PRUNUS VIRUS DISEASES -- From the quarantine point of view the virus diseases of various members of the stone fruits constitute a rather sharply defined group. None are known to affect naturally hosts outside the family; none are juice-transmitted; insect vectors where known are usually single species or closely related species; all these diseases are systemic and persistent; and recognition depends largely on characteristic growth abnormalities in the host. The limited host range simplifies the quarantine problem materially; inability to spread by pruning and other normal operations is also a distinct advantage; but much uncertainty is introduced by the difficulty of sure detection and by lack of adequate knowledge on critical virus and vector relations.

Prunus virus diseases have been outstanding subjects for quarantine action among the States. Not only are Prunus fruits of high economic value, widely grown, and universally popular, but the virus diseases peculiar to these orchard crops are unusually numerous, and at times very destructive. Over 50 of these virus troubles are recognized, of which a large majority are suspected to be indigenous; at least evidence of foreign origin is in most cases not at all conclusive.

State quarantine measures for these diseases have in nearly all instances centered on nursery stock movement, since the fruit and seeds have been shown to transmit these viruses only in exceptional cases. For many States some or all of the Prunus virus troubles are merely included in the normal nursery stock plan of protection. Where quarantines are imposed the State either relies on its own special protective restrictions or the scheme of quarantine at-source is adopted, the latter solution being usually accompanied by active Federal cooperation.

Because of the difficulties in detection, the existence of a symptomless incubation period, and the possibility of symptomless carriers, direct inspection of nurseries is often supplemented by the requirement of a virus-free zone around the nursery, and in some cases its bud-sources. This is a precautionary requirement adopted as the only available means of preventing local virus spread to the nursery plants.

Mention should also be made of the pronounced present trend toward the establishment of indexing procedures intended to maintain virus-free plant sources for use in propagation. This important development represents a distinct step in Prunus virus disease control, although it can only start an orchard with healthy stock and cannot prevent the intrusion of local virus infection during the relatively long life of the orchard afterward.

Some of the Prunus virus diseases appear to have areal limitations. It is not always clear whether these are climatic in nature or correspond with vector distribution or are due to other variable factors. Such limitations must be duly considered in quarantine planning.

In the light of these general features, a summary may be made of the various quarantines dealing with Prunus viruses.

Peach Mosaic (Marmor persicae): Peach mosaic is a troublesome orchard control problem at times in the eight Southwestern States where it occurs, and a persistent campaign is being waged by these States cooperatively with the Federal government to reduce or suppress it effectively in commercial peach plantings. Interstate quarantine interest, however, centers in the problem of preventing spread through nursery stock movement. Certification by the State of this nursery stock for interstate shipment includes maintenance of inspection over the one-mile environs of

nurseries and budwood sources, and early-season removal of all mosaic-infected trees therefrom. Federal and State inspectors combine their forces in a comprehensive program, under general Federal supervision to unify effort over the whole area, and undertake in joint fashion this nursery inspection, the orchard inspection work, and the survey of new territory for mosaic.

This large-scale cooperative attack has been made possible, first of all by State agreement in the common plan; second, by the issuance by the States concerned of a uniform series of practically identifical quarantines; and third, by the character of these quarantines, which being of the at-source type aim to protect distant States from danger of mosaic spread, as well as to serve the internal needs of the issuing State. This whole arrangement may be said to represent the highest plane of organized quarantine effort yet attained in the interstate field.

The peach mosaic problem is a recent development. The disease was found and recognized in 1935; and the project was not organized on its present basis until 1937. The States now actively participating are: Arizona (Quar. Order No. 9; revised, March 31, 1947); Arkansas (Quar. Order No. 1; Nov. 11, 1949); California (Quar. Procl. No. 14, revised, Jan. 29, 1945 and amended Feb. 6, 1947); Colorado (Quar. Order No. 1; May 1, 1942; and Quar. Order 9; Oct. 15, 1946); Oklahoma (Quar. Order No. 1; Aug. 15, 1944, and amended Dec. 15, 1944); Texas (Quar. Order No. 6, amending No. 5; Jan. 5, 1945); and Utah (Quar. No. 1, revised; June 10, 1947).

Mosaic occurs in New Mexico but both the State's nursery production and its commercial peach plantings are not on a scale to justify the cost of this general inspection program.

Two States, Georgia (Quar. Order No. 2; Feb. 4, 1946), and Idaho (Quar. Order No. 21; (N.S.) revised; Aug. 1, 1949) have preferred to protect themselves against peach mosaic by issuing quarantines against the mosaic States.

Peach Phony Peach (Nanus mirabilis): -- Although known as an obscure orchard trouble in Georgia since the eighties, the virus nature of phony peach was not established until 1929, at which time a Federal-State eradication program was undertaken in Alabama and Georgia, backed by State and Federal quarantines. The Federal quarantine (No. 69; June 1, 1929) was revoked March 1, 1933, owing to the widespread distribution determined by extensive surveys. Federal cooperation has been actively continued, however, and the State quarantines with revisions from time to time have remained in effect.

From the quarantine standpoint the phony peach problem closely parallels that in peach mosaic. Each disease is present in somewhat limited areas; both require trained inspection for orchard detection; control in both cases relies on prompt removal of diseased trees; in both constant general survey is needed; and for both quarantine interest centers on prevention of spread through supervision of nursery stock movement. It may be added that both problems are handicapped by lack of knowledge on critical features, and largely for this reason both resort to safety-zone or environs inspection procedure. In phony peach, however, the incubation period is longer (18 months or more) and inspection of budwood sources has not been found necessary owing to failure of transmission by budding methods.

Because of this close correlation Federal cooperation combines the two diseases into a single administrative project, and since 1936, by agreement with the States concerned, a uniform program has been worked out for both, as discussed under peach mosaic. In this common enterprise, inspection resources are pooled for survey, orchard inspection, and nursery inspection; and in the customary way the State certifies for interstate movement the nursery stock found by the combined inspection to be eligible under the general program agreement. It may be noted here that since this program was instituted, no evidence has appeared which would indicate that spread of either disease is taking place by means of nursery stock movement.

No attempt is made here to cite the various State quarantines and their numerous revisions covering the period since 1929. At the present time the State quarantines on phony peach are all practically identical in content, covering, by name, counties in which the disease occurs, and requiring a State-of-origin certificate on all peach or nectarine trees with roots or trees grafted on peach or nectarine roots, out of this infected territory. These States are as follows: Alabama (Quar. No. 1; Mar. 3, 1939); Georgia (Quar. No. 1, revised, Feb. 21, 1949); Illinois (Quar. Procl. as revised March 15, 1947); Louisiana (phony peach disease regulation, revised; July 1, 1937); Mississippi (Rule 64-A; amended, Feb. 14, 1947); Missouri (Quar. No. 1, revised; Feb. 20, 1947); South Carolina (Quar. Order No. 1, revised; Feb. 24, 1949); Tennessee (Quar. Notice No. 11, revised; March 29, 1948); Texas (Quar. No. 5, amending No. 4; Jan. 5, 1945).

It should be noted that Florida is not included, although phony peach is present there; the State's peach culture is too small to justify this type of quarantine action. Again Illinois maintains the standard type of quarantine, although no phony peach has been found there for some years. Finally it is noteworthy that the numerous other peach-growing States appear to accept this protection-at-source method of handling the phony peach problem as affording them an adequate safeguard against the disease.

Peach Yellows and Related Diseases: Five Western States have set up quarantine barriers against introduction of peach yellows, little peach, and peach rosette (_Chlorogenus persicae_ var. _vulgaris_, _C. persicae_ var. _micropersica_, _Carpophthora rosettae_). These measures affect propagating materials of almond, apricot, nectarine, peach, and plum coming from the eastern area of known occurrence of these diseases.

The Oregon Law (Compiled Laws, V. 4, Sec. 35-205; regs. 1946) covers only peach, nectarine, and apricot; includes fruit pits; and requires State-of-origin certification from the quarantined area that such nursery stock was grown in a disease-free area and that the bud source and environs were also free from these diseases. Arizona (Quar. Order No. 8; 1939; revised, Jan. 5, 1945); California (Quar. Procl. No. 11; Jan. 13, 1945); Idaho (Quar. Order No. 3; revised, Aug. 1, 1949) and Washington (Quar. No. 9; Mar. 30, 1945) have practically identical measures, which allow entry of the materials mentioned when certified by the State of origin, but with certain differences. Arizona, Idaho, and California accord shipping approval for counties at origin certified as virus-free by the State authority through annual survey, and require the certification of bud sources and stocks as also virus-free. Washington maintains an embargo against the infected States and requires special certification from noninfected States.

Peach Yellows (_Chlorogenus persicae_ var. _vulgaris_): The State of Virginia maintains in its code (Sec. 905, compiled laws 1945; 1889-90; p. 145, code 1919) an early law making it an offense to bring into or sell within the State any peach tree infected with peach yellows. The actual usefulness of this law is doubtful, owing to the difficulty of establishing before a court that the virus in a specific tree or lot was brought into the State and was not of local origin.

Peach Wart: California (Quar. Procl. 22; July 11, 1947) establishes restrictions on the entry of peach trees and parts thereof from Oregon, Idaho, and Washington, to exclude this virus disease. A State-of-origin certificate is required establishing that the growing ground, the budwood sources, and the environs of these for one-half mile have had no wart during the current and previous season.

Peach X-disease (_Marmor lacerans_): Taking cognizance of the gradual spread of this virus disease in New York and the New England States, and of the presence of a similar disease in Idaho, Utah, and Colorado, the State of New Jersey issued a quarantine (Jan. 17, 1939) shutting out budwood, scions, and other parts of peach from the States mentioned, as well as plants or parts of the chokecherry hosts (_Prunus virginiana_, _P. demissa_, and their varieties). To strengthen this measure, it is required that shipments of peach trees and peach propagating materials into New Jersey from elsewhere shall be marked to show origin.

The disease here referred to is now considered to consist of two entities -- the eastern and the western X-disease (yellow-red virosis). This later distinction would apparently not effect the validity of the New Jersey quarantine.

PEPPER PLANTS -- See under Seedling Vegetable Transplants

PEPPER SEEDS, BACTERIAL CANKER (_Xanthomonas vesicatoria_) -- Puerto Rico (Quar. No. 3; July 30, 1948) requires that all pepper and tomato seeds coming from the mainland must be treated with bichloride of mercury previous to shipment and be accompanied by a State certificate showing that this treatment has been given.

PERSIMMON WILT (_Cephalosporium_ sp.) -- California (Quar. Procl. No. 19; Nov. 10, 1939) has established an embargo on all trees and parts of persimmon except fruits and seeds, prohibiting their entry into the State from elsewhere on account of the persimmon root borer (_Sannina uroceriformis_) and the _Cephalosporium_ wilt. Justification for the embargo rests on the widespread distribution of the root borer and the lack of effective treatment for the internally borne wilt disease.

PINEAPPLE DISEASES, UNSPECIFIED -- The Territory of Hawaii (Reg. 1.2; Aug. 14, 1947) established a general quarantine on pineapple (plants or parts thereof, and fruits) and other bromeliaceous species, on account of certain specified insects and thrips, as well as pests and diseases in general. The object was the protection of the extensive pineapple industry from new outside pests. Under the terms of this measure, the restricted materials are enterable under permit, and may be held for official observation under prescribed detention conditions until release is approved.

A similar procedure is set up by Puerto Rico (Act No. 35 of May 11, 1934; as amended Apr. 15, 1946, and on May 14, 1948). Entry inspection, certificate by the State of origin, and special detention requirements are the outstanding features of this measure.

PLANT PATHOGEN CULTURES -- The propriety of imposing regulations on the interstate movement of living stages of injurious insects or plant pathogens was much discussed in early years. Specific Federal domestic quarantines have at times taken cognizance of the danger of pest introduction into a new area through transportation of these pests and culture materials by

persons who were either irresponsibly unaware of the possible consequences of careless handling or were merely indifferent to this aspect of the situation. In some quarters justification for unrestrained culture movement was sought as a right inherent in the customary freedom of scientific research.

In recent years the trend of thought has tended to reconcile these two conflicting concepts. It is recognized that the research function is not sacrosanct and that a pest let loose in the course of investigation is just as destructive to the country's interest as if it were carried to a new locality by ordinary commerce. Consequently, control over one means of dissemination is as necessary as for the other. Further, with this recognition that national welfare must be the paramount consideration comes repudiation of the claim that supervision over culture movement connotes an unwarranted interference in research freedom. The present viewpoint looks upon culture movement as utterly outside the interest of the quarantine authority, State or Federal, so long as it is made under safe conditions. With this safety provided for, the quarantine administrator is not concerned as to the object of the research or the materials needed for it. Beyond a proper care that transported cultures do not endanger the public welfare, he has no slightest wish to control research in any way. A growing understanding of the two-sided nature of this problem is now building up excellent cooperative relations between quarantine agencies and research specialists, and it is believed that future procedures mutually satisfactory to both points of view can henceforth be easily arranged.

Several States have promulgated restrictions on the entry into them of living stages of injurious pests, which are generally considered to include not only insects but also fungi, bacteria, nematodes, and viruses. The provision in these measures for entry under permit is obviously intended to allow the most liberal possible movement of cultures consistent with safety in their handling, use, and ultimate disposal.

Alabama -- Agric. Laws of Alabama, Annotated, Code of Alabama, 1940, Sec. 461, art. 28, "Introduction of pests and diseases. -- The introduction into this State of any live insect or specimen of any disease injurious to plants, except under a special permit issued by the board or commissioner is hereby prohibited."

California -- Agricultural Code of Calif., Div. 2, Ch. 1, Sec. 110, "It is unlawful to import into or ship or transport within the State, except for the purpose of identification, any pest, live insect or disease, unless such shipment or transportation is authorized under written permit and the regulations of the director or the United States Department of Agriculture....."

Colorado -- State Entomologist Act of April 27, 1937, Sec. 10, "Unlawful to Transport Pests. It shall be unlawful for any person or persons, by any means whatsoever to knowingly transport, into or in Colorado, live pests which may be injurious to agriculture or horticulture in the State, except for scientific purposes, without permission from the State Entomologist."

Florida -- Florida Plant Act of 1927, Sec. 7, "The introduction into this State of any live insect or specimen of any disease injurious to plants, except under a special permit issued by the Board, is hereby prohibited."

Georgia -- The Entomology Act of 1937, as amended March 19, 1943, Sec. 11, "The introduction into this State of any insect in any stage of development or specimen of any disease injurious to plants, except under a special permit issued by the Director of Entomology is hereby prohibited."

Territory of Hawaii -- Regulation three of the Territory of Hawaii (Aug. 14, 1947) brings under restriction all cultures of fungi, bacteria, and viruses entering the Territory. Under a permit system, entry of these cultures may be authorized, subject to stipulated conditions of entry and utilization, and to an inspection procedure to verify identity.

Wisconsin -- Wisconsin Statutes 1943, Ch. 94, Sec. 544, "Permits for shipment of insects and pathogens. No person shall sell, barter, offer for sale, or move, transport, deliver, ship, or offer for shipment, any living insects in any stage of their development, or any living plant pathogens without a permit from the Department of Agriculture, issued upon compliance with the conditions and regulations which the Department is authorized and directed to prescribe .....Such permit shall be issued only after the Department has determined that the insects plant pathogens in question are not injurious to plants, animals, or other materials, if not already present in the State, or have not been found to be seriously injurious to warrant their being refused entrance, if known to be already established within the border of the State. Such permit shall be affixed to the outside of every container or shipment thereof."

PLANTS: CROWN GALL (*Agrobacterium tumefaciens*) -- Since crown gall has practically a universal distribution, and the organism itself can be carried invisibly on plant roots and in attached soil, regulations based on the presence of visible galls must be justified on advantage to the plant grower rather than as a means of preventing actual geographical distribution. Further,

the high value of gall-free plants is unquestioned for some plant species, but less evident in other cases; and there appears to be some variation in crown gall injuriousness as between Northern and Southern States.

When these uncertainties are considered, along with inspection difficulties and limitations, the tendency among the States has been to adopt a compromise attitude toward crown gall. Many States are content to accept plants freed from visible galls as satisfactory; a few would require the rejection of all gall-bearing plants; and still others would object to any stock in which crown gall was present at digging inspection. In most cases, however, these attitudes can be satisfied in the normal nursery inspection procedure, without recourse to special quarantine promulgation.

Arizona appears to be the only State which has established special crown gall restrictions (Quarantine Reg. No. 3; Sept. 1, 1927; revised, May 17, 1944). In this measure the State refuses to accept any out-of-State plant or tree on which crown gall is found visibly present, and if over 50 percent of the plants in any lot show galls the entire lot will be rejected.

PLANTS: OZONIUM ROOT ROT, TEXAS ROOT ROT (Phymatotrichum omnivorum) -- The soil fungus here concerned attacks the root systems of a wide range of plants and can, of course, be spread by nursery stock or other types of rooted plants. The organism is said to be present in soil in at least parts of eight Southwestern States.

Three States attempt to shut out plant materials likely to carry this destructive soil fungus; California (Quar. Procl. No. 13, revised; Jan. 21, 1949); Mississippi (Rule 63; Jan. 1, 1930); and New Mexico (Quar. Order No. 11; June 30, 1937; revised Sept. 8, 1937).

Since the fungus occurs in decidedly patchwork fashion throughout the eight States, which include both California and New Mexico, the object of each quarantine is to prohibit shipment of soil, plants with soil, and rooted plants from the various root-rot areas, but not to extend restrictions beyond this justifiable minimum. New Mexico designates these areas by counties. California is less specific as to areas and relies on a certificate of the State of origin to establish eligibility for entry; and Mississippi quarantines on a State basis and depends on the certificate also.

PLUM VIRUS DISEASES -- See under Prunus Virus Diseases

PRUNE VIRUS DISEASES -- See under Prunus Virus Diseases

RHODENDRON, Ovulinia azaleae -- See under Azalea

RUBUS DISEASES -- The diseases of this group, which includes various bramble plants of blackberry, raspberry, and dewberry type, have given been considerable quarantine attention. Although widely varied in nature and behavior, the virus diseases, orange rust, and crown gall, with which quarantines are largely concerned, are seen to be widely distributed so that the quarantine objective is not so much to protect large areas from the introduction of a new pest as to avoid the disadvantages of bringing the pathogen into new plantings, or the infection of adjacent plants, or the contamination of clean soil. Thus the aim in general is to protect the individual grower's interests rather than the geographical area. Because of this viewpoint, the regulations imposed can be looked upon as special cases in the general scheme of nursery stock sanitation. The additional restrictions and requirements demanded in the States of origin and the certification procedures adopted all fall readily into the nursery stock pattern. Further, virus disease relations in the Rubus group essentially duplicate those encountered in seed potato certification, so that one might expect to find a certain parallelism of action in these two fields.

While this close relationship with the nursery stock pattern has been recognized in the quarantine promulgations of most States, which lump together the diseases of brambles or of raspberries, a few States have imposed individual quarantines for specific diseases. In a few cases also slight tolerances are allowed.

Seven States regulate the entry of raspberries and require some form of certification by the State of origin. The North Dakota regulation of 1931 covers virus and other diseases; so does New York (Order 23, amended Mar. 6, 1925); the other five in this group exhibit considerable uniformity of viewpoint, probably the happy result of Central Plant Board discussion and agreement. Wisconsin (Order No. 7; Jan. 1, 1930); Kansas (Rules and Regs. 7-1-29; June 1948); Minnesota (Quar. No. 6, revised, April 1, 1928); Michigan (Reg. No. 601; Feb. 4, 1947); and Ohio (Reg. Summary, Jan. 1, 1942), all deal with virus diseases and orange rust. All these five States, as well as New York, demand that the inspection and certification given by the State of origin shall be substantially equivalent to the protective procedure in effect in the recipient State. In addition, Ohio includes crown gall; Pennsylvania (bramble plant certification, May 15, 1939) apparently accepts the standard nursery stock certificate for the general field of Rubus plants but provides specially for crown gall inspection at destination. Washington State (Order No. 17; July 11, 1933) covers all berry plants along with strawberries and includes crown gall among the pests and diseases given as the reason for regulation.

SHALLOT DISEASES -- See under Onion

SORGHUM DISEASES -- See under Grass Plants

STRAWBERRY PLANTS -- See under Rubus Diseases

TOMATO PLANTS -- See under Seedling Vegetable Transplants; also under Potato, Root Knot Nematode

WALNUT BUNCHY DISEASE (Virus) -- This virus trouble has been recognized since 1913 as a virus trouble in the Southeastern States and has been observed since then from the Gulf States to Michigan. Its witches'-broom effect is particularly important on the butternut, Juglans cinerea, and on the Persian or English walnut commonly cultivated. The disease has not been reported west of the Rockies.

Owing to the growing importance of walnut culture in California, that State has issued a quarantine (Quar. Procl. No. 12; Jan. 28, 1949) as a protection against bunchy disease introduction from eastern sources. The action taken (1) prohibits movement from all States east of the Rocky Mountains of all plants and propagative parts (except seeds) of both wild and cultivated forms of Juglans; and (2) allows entry from States west of the Rockies under certificate establishing this western origin.

Because of a reasonable assurance that the Pacific Coast States are still free from this disease, and the negligible movement of walnut propagating stock into California from the East, the measures taken give considerable assurance of being able to prevent spread.

The quarantine cited also covers propagating materials of hickory and pecan trees (Carya spp.) in a similar way on account of certain nut tree casebearer insects (Acrobasis spp.).

WESTERN CELERY MOSAIC (Virus, Chlorogenus callistephi var. californicus) -- Two States, Arizona (Quar. Order No. 16; June 28, 1945), and Colorado (Order H; Feb. 1, 1948; amended 1949), attempt to protect the celery industry in each from this virus malady by prohibiting the entry of seedling host plants from all out-of-State sources. Since freedom from the disease is indicated for both States, these quarantine measures aim to protect the State as a whole, as well as its individual celery growers. The finished commercial plant product is not affected by the quarantine; risk of transmission in celery table stock is regarded as negligible.

VEGETABLE TRANSPLANTS -- Although the common vegetable seedlings and rooted cuttings (cabbage, onion, tomato, sweetpotato, pepper), as grown and distributed in quantity for field and garden crop production, are not considered in the category of nursery stock, their movement interstate involves much the same elements of risk as the woody plants of nursery origin commonly designated as nursery stock. Because of this largely artificial distinction, it has been a usual custom to treat these vegetable plants as a separate quarantine subject although the quarantine procedure observed for them closely follows that employed for the nursery stock proper.

In nearly all States the restrictions and requirements placed on vegetable transplant production are established with a view to avoiding pest dissemination within the State itself, and the inspection and certification procedures involved are in general accepted as providing satisfactory protection by other States. Because transplants can be quickly and universally grown, and can be readily distributed in channels outside of quarantine control, this regulatory supervision over commercial production at source represents about the best practicable service that quarantines can render. The effectiveness of these methods is largely dependent on the extent to which this control system is supported by individual growers and by the general public.

SEED SWEETPOTATOES AND PLANTS -- Outstanding in the vegetable transplant category are the so-called slips or draws of sweetpotato. While sweetpotatoes and these rooted cuttings are generally regulated to prevent spread of the sweetpotato weevil (Cylas formicarius) several States also take cognizance of diseases of this crop in their restrictions on interstate movement. Alabama (Reg. 2; June 1, 1948) requires a certificate from the State of origin on seed sweetpotatoes and sweetpotato plants entering the State. Oklahoma (Reg. No. 20; 1944) makes this certificate requirement for sweetpotato plants, but provides as well for inspection on arrival. South Carolina (Sweetpotato Regs.; March 1449) requires corrosive sublimate soak for seed sweetpotatoes and disinfection of frames and bedding with formaldehyde in the State's propagation procedure, and demands this also for out-of-State seed stock, which must be certified and entered under a permit-tag arrangement. Arkansas (Rule 18; 1937) also depends on the State-of-origin certificate and the permit-tag system for sweetpotato plants, and allows their entry only from other States where weevil is not known. Mississippi (Rule 23B, amended; Oct. 8, 1941), and Missouri (Reg. No. 11(G); April 15, 1946) also require the State-of-origin certificate and the permit-tag feature for seed sweetpotatoes and sweetpotato plants. Georgia (Sweetpotato Regs.; June 1, 1949) and Louisiana (Certified Seed Reg. No. 9; April 1, 1949) adopted a similar certificate and permit system, but go further to establish standards for planting stock production within the State and then require seed sweetpotatoes or plants entering from outside to meet these standards.

It will be noted that all these restrictions and requirements are essentially of the nursery stock type, following the nursery stock plan in slightly modified or accentuated form. The quarantines by Kansas (Quar. No. 9; March 15, 1947) and Texas (Quar. Procl. No. 48 A; March 7, 1949) are more definitely of true interstate character. In both these an embargo is placed on seed sweetpotatoes and plants (and in the case of Texas on all sweetpotatoes) coming from the ten States where the internal cork disease (virus) is known to exist, in order to prevent the introduction of this new and undesirable sweetpotato trouble. In Kansas the whole State is thus given quarantine protection; the protected part of Texas comprises 144 counties.

These two quarantines should probably be looked upon as precautionary measures, representing the most effective protective effort the State could make in the absence of adequate knowledge on distribution, nature, host, and symptomatic relations of the disease, or of its potential damage, means of spread, or amenability to inspection and certification methods. This situation well illustrates a frequent quarantine dilemma -- a sincere urge to serve the public welfare by taking the most hopeful course of action, but without the comforting assurance that this will duly accomplish the purpose or even that it will prove of any real benefit.

SEEDLING VEGETABLE TRANSPLANTS -- Seedling transplants are also an item of considerable importance in interstate trade, especially those of tomato, cabbage, onion, and pepper. For the most part these move freely interstate with or without certification by the State of origin. A few States however impose certain restrictions on interstate movement as a protection measure against disease in general.

Arkansas (Rule 18a; Dec. 22, 1941) allows entry of cabbage, onion, and tomato plants under a permit arrangement based on field inspection and certification by the State of origin; and Oklahoma (Seed Law, Reg. 20; 1944) follows the same procedure for plants of cabbage, onion, pepper, and tomato. A similar control is exercised by South Carolina (Regs. T.1, T2, T3, C2, C3; Jan. 1, 1924) over cabbage and tomato plants entering the State.

ONION, SHALLOT, DISEASES -- Louisiana regulates the production of onion bulbs and seeds (Cert. Seed Reg. 7; Aug. 15, 1945) and shallot seed (Cert. Seed Reg. 11; Aug. 15, 1949) within the State and demands the same certification procedure for these products entering from other States. These measures are intended to keep planting stocks free from mildew, smut, pink root, yellow dwarf, and mosaic.

PEPPER BACTERIAL CANKER, (*Xanthomonas vesicatoria*) -- Puerto Rico (Quar. No. 3, revised; July 30, 1948) attempts to prevent establishment of this disease in the Island's cultures by a requirement of disinfection at origin for tomato and pepper seeds, this treatment to be verified by an accompanying certificate.

SUGARCANE DISEASES -- Louisiana (Sugarcane Quar.; Oct. 15, 1928) and Hawaii (Reg. 1.1, revised; Aug. 14, 1947) have attempted to prevent the introduction of insect and disease pests into their important sugarcane cultures by prohibiting the movement of canes or parts thereof likely to carry pests, except under a permit system which can set up effective safeguards against pest entry and, at the same time, avoid artibrary and useless interference with normal commerce and the proper development of the sugar industry (See also under Grasses).

RICE SEED DISEASES -- Louisiana (Cert. Seed Reg. No. 10; Aug. 24, 1949) has set up standards and procedures for the production of quality rice seed within the State. Incidental to this certified seed program the State sets up requirements for rice seed introduction from elsewhere, based on what is essentially certification by the State of origin. Since neither the local program nor the exterior requirements refer to specific rice diseases, the inclusion of this measure here is questionable.

STRAWBERRY, GENERAL DISEASES -- Three States, Alabama (Nurs. Regs., revised; Sept. 24, 1943); Arizona (Quar. Order No. 10, Reg. 1; Jan. 25, 1946); and Kansas (Nurs. Stock Rules and Regs.; June 10, 1948), make a special feature of strawberry plants, largely, it may be surmised, because they fall outside the woody-stemmed plants customarily classed as nursery stock. The requirements for these plants are of the usual nursery stock character involving certification at point of origin as to disease freedom, and in the case of Kansas evidence of a double field inspection if so listed for sale.

STRAWBERRY RED STELE, (*Phytophthora fragariae*) -- Three States, Kansas (Nurs. Stock Rules and Regs.; July 1, 1932); Michigan (Reg. 609; Aug. 29, 1946); and New Jersey (Regulations, Feb. 14, 1939) have taken special cognizance of this strawberry trouble, and require the State-of-origin certificate to assure freedom from this fungus.

POTATOES: SEED POTATOES, VARIOUS DISEASES -- The development of seed potato certification in this country since about 1914 has been spectacular. It is a success story of truly epic quality, since the movement has nearly doubled the national per-acre yield in this period. It is particularly noteworthy that this astonishing result has been achieved with a minimum of

resort to quarantine and regulatory methods; it has been accomplished largely by helpful technical guidance, cooperative enterprise, and on the part of the State by official service rather than by legal compulsion. In this respect it serves as a sound and healthy model for many other future problems.

The general procedure followed over and over in various States involves freeing a selected seed lot from virus diseases, grading, packing, and storing the product according to acceptable high standards, and distributing it under certificates establishing its seed quality. Although this certification has been variously sponsored by State agencies, by associations, by growers' cooperatives, and even by private firms, experience has bred a widespread confidence in the certification plan, and "certified seed" is directly or indirectly utilized for planting about 75 percent of the country's potato crop.

A great bulk of this certified seed production, as well as much uncertified stock, moves freely in interstate commerce because of the faith of growers and regulatory authorities alike in the over-all effectiveness of the certification system. Quarantine actions for certain specific potato diseases are noted below, but only a few States have considered it necessary to regulate the entry of seed potatoes as a general protection against potato diseases. These are Alabama (Reg. No. 3; Oct. 9, 1941); Arkansas (Rule 70, amended; Dec. 22, 1941); Idaho (Quar. No. 29; Jan. 31, 1944); Louisiana (Irish seed potato Reg., revised; Oct. 15, 1944); Mississippi (Rule 60, amended; May 9, 1938); Oklahoma (Quar. Order No. 5, revised; Jan. 1, 1944); and South Carolina (Reg. 16 Q, revised; Jan. 9, 1939).

The measures of all these States depend on certification by the State of origin; all but Mississippi and Idaho stipulate sealed and tagged containers; Arkansas, Idaho, and Louisiana restrict entry for seed purposes to certified stocks; inspection on arrival is emphasized by Louisiana and Oklahoma; Idaho regulations specifically exclude all seed lots with ring rot; Louisiana and Alabama prescribe tolerances to be met for all diseases, and Oklahoma sets up tolerances for diseases detectible by tuber inspection; otherwise, the disease inspection standards of the producing States are accepted.

POTATO BACTERIAL RING ROT (Corynebacterium sepedonicum) -- That the sudden appearance and rapid spread of this troublesome potato disease was not accompanied by numerous costly and disruptive quarantines is perhaps attributable to a general confidence in the national system of disease control which has been so outstandingly successful for this crop over the years. While ring rot has been a difficult local problem, particularly in seed potato production, only a few States have attempted to strengthen their control efforts by quarantine methods of interstate character, and in these cases a special objective is apparent.

Idaho (Quar. Order No. 29; Jan. 31, 1944) excludes seed potatoes affected by ring rot; Minnesota (Quar. No. 7; May 15, 1946) aims to preserve certain areas in the State as a seed potato source free from ring rot; Texas (Quar. Procl. No. 40-E; Dec. 5, 1946) likewise would keep an important potato area free from the disease; and Washington (Quar. Order No. 31; March 18, 1948) depends on the seed certification system to keep ring rot out of seed potatoes coming in from other States.

POTATO GOLDEN NEMATODE, Heterodera rostochiensis -- Because of its destructive character and persistence in soil, the golden nematode presents a definite threat to the widespread and nationally important potato industry of this country. However, the cooperative regulatory and control program undertaken by the Federal Department of Agriculture and New York State appears to have been generally accepted as protecting the potato interests of other States, and quarantine measures have been taken only by three New England States, largely to enable them to prevent irregular or unauthorized truck shipments of potatoes from the only known infested area, which is located in Long Island. These special measures by Maine (Executive Order No. 48; June 20, 1947); New Hampshire (Quar. Order No. 1; Aug. 15, 1947); and Vermont (Quar. No. 5; Aug. 25, 1947) all prohibit the movement of potatoes from the infested area into or through the State.

POTATO LATE BLIGHT, (Phytophthora infestans) -- In recent years evidence has accumulated emphasizing the role of potato tubers in carrying over the late blight fungus. While important enough in areas subject to blight or in favorable blight seasons, this carry-over may be a critical factor in generally blight-free areas or in years with low blight incidence. Seed potato certification standards normally attempt to keep late blight tuber rot out of certified stocks, and this procedure apparently satisfies most State requirements.

Texas is the only State which has imposed special late blight restrictions (Quar. Procl. No. 40 E; Dec. 5, 1946). Seed potatoes entering the State are required to have a certificate by the State of origin, establishing freedom from late blight (also bacterial ring rot and tuber moth), when destined to three counties in the State for which protection is desired.

POTATO, ROOT KNOT NEMATODE, Heterodera marioni (Meloidogyne sp.) -- Since this nematode is said not to occur within the State of Utah, a State quarantine (Quar. No. 2, revised; June 10, 1947) requires a State certificate of freedom from this root pest in connection with all potatoes and tomato plants from eight Southern and Western States and the Territory of Hawaii.

TOBACCO ETCH (Virus - Marmor erodens var. vulgare) -- A Georgia quarantine (Quar. No. 8; Nov. 15, 1948) attempts to protect the tobacco culture of the State from this virus disease by prohibiting the movement of tobacco plants from two counties within the State where infection exists, and into Georgia from three Florida counties. This prohibition is safeguarded by requiring certification by the Florida Plant Board of tobacco plants from elsewhere in Florida.

TOBACCO BLUE MOLD (Peronospora tabacina) -- The readiness with which this fungus is carried northward each spring has discouraged any attempt to use quarantine methods in the numerous sections of the East where tobacco culture is prominent. The existence of effective control methods in the critical seedbed stage also serves to weaken any thought of resort to quarantine measures of dubious worth. However, the special importance of the tobacco crop to the Territory of Puerto Rico and the natural sea protection enjoyed by the Island appear to justify attempts to exclude this disease from mainland sources, and an insular quarantine (P.R. Quar. No. 6; revised; July 30, 1948) is in effect requiring all tobacco seed of mainland origin to be routed through the insular quarantine service and to assure that such seed is disinfected either at source or on arrival; the quarantine also prohibits movement into Puerto Rico of shade cloth previously used on mainland tobacco fields.

TOMATO BACTERIAL CANKER -- See under Pepper

TOMATO ROOT KNOT NEMATODE (Heterodera marioni) -- To protect six counties from the introduction and spread of root-knot nematode Virginia has imposed a quarantine (Quar. No. 6; May 1, 1940) providing that all tomato plants moving into this six-county area from elsewhere in the State or from other States shall be accompanied by a State certificate establishing their freedom from visible root knot and from other destructive insects and plant diseases. This quarantine is recognizable as merely a special case in the general plan of nursery stock procedure.

GENERAL COMMENT

In reviewing this sketchy summary of the present status of State quarantines affecting interstate commerce, the interest of the plant pathologist will doubtless have been aroused by several features of general import. In the first place, it will be noted that relatively few of these interstate quarantines aim at true areal protection; the majority simply attempt to reduce the chances of pathogen introduction or endeavor to keep individual plantings or soil tracts free from the intruder.

It is strikingly apparent also that a great number of these measures are merely extensions or special cases of the common procedure pattern adopted for regulating nursery stock. Many of them are actually set forth in State nursery stock regulations, and if the arbitrary conception of "nursery stock" were broadened to comprise a wider range of propagating materials than the woody plants generally included, more of these quarantines would undoubtedly fall readliy into this category where, in spite of legalistic custom, they truly belong.

A third point which deserves mention is the tendency to add interstate features to the State's own internal program set up under regulation for local disease control. In a number of cases the interstate element in these measures is obviously tagged on in vague and indefinite terms as a rounding out of the protective scheme, but is not given the care and attention a true interstate quarantine would seem to demand.

Again, mention has been made in several instances of the helpful activity of the plant board system in the interstate quarantine field. The evidence from this study indicates that the several plant boards have exerted a gratifying influence in bringing about agreement not only in the terms but also in the basic conceptions of measures proposed among State groups. This trend toward unification of viewpoint and procedure is particularly evident in recent quarantine promulgations, and with the helpful operation of the Plant Board organization it can be expected to exhibit itself increasingly in future problems affecting a number of States.

Still another feature will be observed by the pathologist in this quarantine summary -- the pronounced patchwork effect of our interstate quarantine measures. Even with due allowance made for regional, climatic, and crop differences, and for legal and financial limitations among the States, there is still observable a certain inconsistency in the application of quarantine methods to the same problem by individual States. We can only regard this irregularity of front toward a common enemy as evidence of the newness and incompleteness of the quarantine system which the Nation is in process of developing. It may be expected that time and experience will eventually bring into the picture a unity so obviously lacking at this stage of progress.

From the plant pathologist's standpoint perhaps the most significant feature brought out in this summary is the unfortunate necessity of attempting quarantine action before adequate knowledge is available on which sound procedure may be confidently based. Lack of vital information has plagued quarantine effort from the very beginning, and it still vexes the quarantine planner at every step. It cannot be considered his sole responsibility, however. The current conception of a quarantine regards it as a community effort to which all who can should contribute. On this view the plant pathologist is called on to participate along with the other groups and elements concerned. If quarantine methods are to be helpfully utilized in the war waged by humanity against crop pests, the pathologist's aid is indispensable not only in furnishing the facts and information so urgently needed for success, but also, by virtue of his special viewpoint and experience, in actively helping to plan a healthy future course for the quarantine movement.

DIVISION OF DOMESTIC PLANT QUARANTINES, BUREAU OF ENTOMOLOGY AND PLANT QUARANTINE, AGRICULTURAL RESEARCH ADMINISTRATION, UNITED STATES DEPARTMENT OF AGRICULTURE

HISTORY OF BOTANY AND PLANT PATHOLOGY AT ALABAMA POLYTECHNIC INSTITUTE

James A. Lyle

Work in botany and plant pathology was initiated at the Alabama Polytechnic Institution in 1883. In that year P. H. Mell was appointed as botanist of the Alabama Agricultural Experiment Station, serving in that capacity until September 1902. He was author of bulletins on the woods, grasses, and flora of this State.

Although the department of botany and plant pathology at the Alabama Polytechnic Institute has always been primarily a teaching department, some noteworthy contributions have been made in research. Several notable men have been associated with the department. The most outstanding of these was George F. Atkinson, who was appointed late in 1889 to fill the just created position of biologist. He spent only three years at Auburn, but he accomplished more in that length of time than any other member of the department before or since his time. Atkinson's publications covered a variety of subjects ranging from pure mycology to physiological disturbances and even entomological problems.

From the standpoint of Alabama's agriculture Atkinson's most important work was on cotton diseases. He was the first to show conclusively that the "rust" of cotton could be corrected by applications of potash fertilizers. This work, published in 1892, resulted in a revision of fertilizer practices in Alabama, and probably did more than any other one thing to improve yields of cotton in the South at that time. Atkinson also made major contributions to our knowledge of other cotton diseases. He isolated and named the fungus causing Fusarium wilt. He published three experiment station bulletins describing the root-knot nematode disease, leaf blights, damping-off, anthracnose, angular leafspot, and "areolate mildew". Atkinson probably contributed more to our knowledge of cotton diseases than any other man before or since his time.

Atkinson was succeeded in 1892 by J. M. Stedman, who published papers on boll rots of cotton and on blights of fruit trees. Stedman held this position until 1895, when he in turn was succeeded by L. M. Underwood, who served as biologist for one year.

F. S. Earle was appointed as biologist in August, 1896. He and Underwood published a paper designated as "A Preliminary List of Alabama Fungi." Earle later published an article on the flora of Alabama. He resigned in 1901, and was succeeded by E. Mead Wilcox. Wilcox remained until July 1, 1908. During his tenure at this institution, he published several bulletins on diseases of oak, apple, cherry, peach, pear, plum, and sweetpotato.

F. E. Lloyd was appointed botanist and plant physiologist on November 1, 1908. He published papers on coloring of persimmons, leaf water and stomatal movement of cotton, and other physiological material. He also wrote a monograph on guayule. Lloyd resigned on September 1, 1912.

F. A. Wolf served as plant pathologist of the Experiment Station from 1911 until January 1, 1916. During this period, he wrote many articles on the diseases of apple, citrus, cotton, eggplant, peanut, peach, rose, and walnut. Wolf's work on Cercospora leafspot of peanut was another landmark. He described in detail the life history of Cercospora personata. It was more than 20 years before any other significant contributions were made to our knowledge of this disease.

J. S. Caldwell succeeded Lloyd as botanist and plant physiologist on September 9, 1912, and remained at Auburn until January 1, 1916. Among articles published while here was the one he wrote on natural wilting of plants.

W. J. Robbins was botanist and plant physiologist from February, 1916, to July, 1917. During his stay he published an article on the cause of the disappearance of cumarin, vanillin, pyridine, and quinoline in the soil.

On September 1, 1916, G. L. Peltier was appointed plant pathologist to succeed Wolf. Peltier's work was devoted mainly to citrus canker. He published several papers on various phases of this disease. Peltier resigned April 1, 1920.

On September 1, 1917, W. A. Gardner was appointed to succeed Robbins, and on July 1, 1918, was made head of the Department of Botany. Gardner published papers primarily on soil toxins.

Robert Stratton was assistant professor of botany from January 1, 1918, to July 1, 1920.

On September 15, 1919, E. F. Hopkins was appointed associate plant pathologist to devote his time to the study of diseases of cereal and forage crops. He resigned on April 1, 1920.

Peltier and Hopkins were succeeded by A. F. Thiel, who held the position of acting plant pathologist from April 1 to November 15, 1920.

G. R. Johnstone was assistant professor of botany from September 1, 1920, to July 1, 1923.

Johnstone's field was that of plant physiology, and while at this institution he worked on a physiological study of the sweetpotato. In conjunction with E. R. Miller and C. A. Cary, he published on the poisonous plants of Alabama.

A. H. W. Povah was appointed plant pathologist on July 1, 1921, which position he held until he resigned in April, 1922.

L. E. Miles accepted the position of associate plant pathologist on September 1, 1922, a position which he held until July 1, 1924, when he transferred to full-time extension work. He published papers on the dry-rot of buildings and stored construction materials.

C. C. Zeliff was assistant professor of botany from July 1, 1922, to July 1, 1923.

M. L. Blain was appointed associate plant pathologist on July 1, 1924. M. L. Palmer was appointed at this time as assistant in botany from July 1, 1924, through July 1, 1927. On July 1, 1927, G. L. Fick was appointed to fill the vacancy created by the resignation of Palmer. In 1928 Blain resigned. Research projects included studies of the physiology of the satsuma orange, the phyisology and diseases of sweetpotatoes, pecan scab, and soil toxins.

In 1929, J. L. Seal was appointed as associate plant pathologist and G. L. Fick was advanced to the rank of assistant botanist. E. V. Smith was appointed as assistant in botany in 1931. From 1929 to 1932 research projects were devoted to a continuation of the sweetpotato and satsuma studies, together with studies on the diseases of winter pea and vetch, and the life history of nutgrass. With the resignation of Gardner in 1932, J. L. Seal was made botanist of the Experiment Station and head of the Department of Botany and Plant Pathology.

The staff was unchanged from 1932 to 1936. During this period the research projects included studies of small grain, winter pea, and vetch diseases, and life histories of nutgrass and wild garlic and their control.

In 1936, at the untimely death of G. L. Fick, E. V. Smith was appointed as associate botanist. In this same year J. R. Jackson was appointed as assistant botanist and H. M. Darling as assistant plant pathologist (cooperating with the State Department of Agriculture). Darling was located at the Gulf Coast Substation, near Fairhope, Alabama, to work primarily on Irish potato diseases.

Darling resigned in 1941 and was replaced by T. R. Wright. T. H. King was appointed as an instructor in botany and plant pathology on September 15, 1941. In May, 1942, he was granted a leave of absence and started service in the U. S. Army. D. A. Preston was appointed to fill the vacancy. In 1944 Coyt Wilson, who had served as assistant in botany from 1938 until 1941, was appointed as assistant plant pathologist, and E. V. Smith became assistant dean and director in the College of Agriculture the same year. R. L. Self was appointed as instructor in botany and plant pathology from October, 1945, to June, 1946, H. E. Brewer was appointed as assistant professor of botany in July, 1946. Brewer filled the vacancy created by the termination of T. H. King's leave of absence. R. B. Stevens was appointed as associate professor of botany in July, 1946. T. R. Wright and R. B. Stevens resigned in June, 1947. J. R. Jackson resigned in September, 1947. From 1936 to 1947 research studies were devoted to cotton seed treatment tests, peanut, winter pea, vetch, and Irish potato diseases, the life histories and control of Cherokee rose, nutgrass, Bermuda grass, wild garlic, and wild onion, effect of pasture improvement on weed populations, plants poisonous to livestock, and plant food for fish and farm pond management. Numerous articles were published in scientific journals and as Experiment Station circulars and bulletins.

H. E. Brewer became associate botanist in July, 1947. In September, 1947, K. H. Garren was appointed as associate professor of botany, and D. E. Davis and H. S. Ward, Jr., were appointed as assistant professors of botany. J. A. Lyle was appointed assistant plant pathologist on October 15, 1947. Brewer resigned in January, 1949. J. F. Ferry was appointed as associate professor of botany, in February, 1949, and R. L. Self was appointed to a similar position in April, 1949. W. P. Orr was appointed as graduate assistant in botany in March, 1949.

At the present time research programs are devoted to investigations on the diseases of peanuts, forage, legume, and grain crops, and vegetables. In the peanut disease program, a cooperative arrangement has been developed with the Department of Zoology-Entomology. Major emphasis is being placed on the development of practices that will control diseases and insects in one operation. The work on forage crops, legumes, and grain crops is coordinated with the plant breeding work done by the Department of Agronomy and Soils. Studies on vegetable diseases, in recent years, have been limited to field trials of fungicides on potatoes and tomatoes. This project is being expanded to include studies on the epidemiology and control of the major diseases of pepper, tomato, potato, sweetpotato, cabbage, bean, peach and strawberry. A limited amount of work is being devoted to forest and ornamental diseases.

UNITED STATES DEPARTMENT OF AGRICULTURE

Plant pathologists of the United States Department of Agriculture have obtained research data for several publications, in whole or in part, in Alabama.

A. L. Smith has been stationed at Alabama Polytechnic Institute since 1946. His research is devoted to breeding cotton for disease resistance and to soil fumigation for control of cotton diseases. He works cooperatively with the Department of Agronomy and Soils.

D. L. Gill has been stationed at Spring Hill, Alabama, since 1946. While there he has been working on the diseases of ornamental plants, particularly diseases of azaleas and camellias.

ALABAMA POLYTECHNIC INSTITUTE, AUBURN

A BRIEF HISTORY OF THE DEVELOPMENT OF RESEARCH IN PLANT PATHOLOGY IN ARKANSAS

V. H. Young

INTRODUCTION

Although the University of Arkansas was founded in 1871, there is no evidence from the available records that either teaching or research in the field of Plant Pathology was carried out prior to the establishment of the Arkansas Agricultural Experiment Station under the Hatch Act in 1887. Records show that a limited amount of teaching and research in Plant Pathology were carried out in the Department of Horticulture during the period 1887-1909. The Department of Plant Pathology was established in 1909.

RESEARCH IN PLANT PATHOLOGY PRIOR TO 1909

The period 1887-1909 seems to have been largely a period of observation and exploration so far as plant disease research was concerned. At least three early members of the staff of the Department of Horticulture, Professors J. T. Stinson, Ernest Walker, and J. Lee Hewitt, reported in the bulletins of the Experiment Station on the presence of such diseases as apple scab, apple bitter rot, apple cedar rust, pear blight, apple sooty blotch, apple blotch, downy mildew of grapes, black rot of grapes and strawberry leaf blight (apparently largely Mycosphaerella leaf spot although leaf scorch seems also to have been present). During this period, large numbers of apple, grape, and strawberry varieties were planted in variety tests and the notes made regarding varietal resistance and susceptibility are of historical interest. In one of the first bulletins of the Arkansas Experiment Station, Dr. Wm. Trelease is listed as "Consulting Botanist." It seems uncertain that Dr. Trelease was ever actually in residence.

In 1896, Stinson reports submitting a new apple disease to L. H. Bailey and B. T. Galloway. The former is reported to have suggested the name "Skin Blotch" for this trouble. Galloway identified the organism present as Leptothyrium pomi. It seems evident that "Sooty Blotch" was the disease under consideration.

During this early period many trials were made of various spray materials including bordeaux mixture and ammoniacal copper carbonate spray. Notes on the control of apple scab, apple bitter rot, downy mildew of grapes, black rot of grapes, and strawberry "leaf blight" are given. Apple spraying on a commercial scale was reported in 1894 and it is apparent that control of fruit diseases by spraying was a well established practice in the State by 1896.

During the period 1887-1909 several other diseases are mentioned casually and mention is also made of the use of copper sulphate dips for control of smut in wheat.

PLANT PATHOLOGY SINCE 1909

The Department of Plant Pathology was established in 1909 as a teaching and research department. From the very start it is apparent that the work of the department was divided among teaching, research, and extension work. In 1917 the Arkansas State Plant Board was established with the Head of the Department of Plant Pathology as an ex-officio member of the Board.

For a brief period during World War I an Extension Plant Pathologist, M. S. Ensign, was hired and on November 1, 1949, Dr. Robert Emge (Ph. D., Illinois) became Extension Plant Pathologist. In the meanwhile all of the normal activities of an Extension Plant Pathologist have been carried out by the staff of the Department of Plant Pathology. This work has been valuable to the Department since it brought the staff more closely in contact with the economic plant disease problems of the State.

RESEARCH PROGRAM 1909-1950

As previously noted, the period prior to 1909 was one of observation and exploration with little original research in Plant Pathology. After 1909 there was a period which might be called a "period of orientation." The staff members for at least four or five years were primarily trained in Horticulture with little graduate training in Plant Pathology. Several of these men remained only one or two years and seem to have left little or nothing behind in the way of published research.

Professor J. Lee Hewitt, B.S., Missouri, was for several years prior to 1909 a member of the staff of the Department of Horticulture. In 1909 he became the first Professor of Plant Pathol-

ogy and the first Head of the Department of Plant Pathology. It appears that he was forced by the demands of the Northwest Arkansas apple growers to devote much of his time to a study of apple diseases. As early as 1911 he was joint author with the Entomologist of a publication dealing with the diseases and insects of the apple. Later he published work on apple spraying and on the fire-blight disease in Arkansas. In 1913 Hewitt and Truax published the results of their first studies of "Apple Measles", a disease whose etiology still remains comparatively obscure, although Dunegan and Isely showed that at least a part of what Hewitt had called "Measles" was the result of oviposition punctures made by certain leaf hopper species. Hewitt's work on "Apple Measles" is perhaps his most important contribution to our knowledge of plant diseases. In 1912 Hewitt also reported briefly on "Rice Blight" now known as "Straighthead" which Tisdale later showed to be of physiogenic origin.

During the period from 1909-1917 when J. Lee Hewitt was head of the Department of Plant Pathology several young men were associated with the Department for brief periods. Ashleigh P. Boles, B.S., Arkansas 1908, was Adjunct Professor of Plant Pathology 1909-1910 and for many years since has been prominent in the Agricultural Service of the Missouri Pacific Railroad. John S. Stahl was Adjunct Professor during the year 1910-1911 and was succeeded by Harold E. Stevans, B.S., Kentucky State, M.S., Illinois, who was Adjunct Professor during the year 1911-1912. He was followed by Hartley E. Truax, Instructor of Plant Pathology 1912-1913.

In 1913 Walter S. Fields, B.S., Michigan Agricultural College, became Instructor of Plant Pathology and in 1916 he became Assistant Professor of Pathology. He resigned in 1918. All of the above listed men were apparently young and just starting their careers. Generally speaking their time at the Arkansas Experiment Station was too short to allow them to complete much in the way of research.

Dr. John A. Elliott, A.B., Fairmont College, A.M., Kansas, Ph. D., University of Illinois, came to the headship of the department in 1917, succeeding Hewitt who went to the employ of the Arkansas State Plant Board. Elliott was the first well-trained Plant Pathologist to be employed by the University. His work on the genus Alternaria prior to his arrival in Arkansas is recognized as an important contribution to our knowledge of this important genus of plant pathogens. Elliott's training under F. L. Stevens and others at Illinois had prepared him for a long and useful career in Plant Pathology which was cut short by his untimely and tragic death at the height of his career early in January 1923.

During the five and a half years that Elliott was Plant Pathologist of the Arkansas Agricultural Experiment Station, he was interested principally in diseases of cotton and tomatoes. Elliott applied himself principally to the control of angular leaf spot, seedling blights, and Fusarium wilt. He was one of the pioneers in cottonseed treatment research and showed conclusively that angular leaf spot can be controlled on a commercial basis by the sulfuric acid delinting method.

Having been well-trained in Mycology under Stevens, Dr. Elliott was greatly interested in discovery of new disease-producing organisms. The Ascochyta disease of cotton which he first reported in this country and which under the favorable weather conditions that existed for a few years, caused serious local damage, interested him greatly. His work on cotton is summarized in two bulletins entitled "Arkansas Cotton Diseases" and "A New Ascochyta Disease of Cotton."

During his brief time at Arkansas, Elliott selected and developed several wilt-resistant tomato strains which were grown and highly regarded by a number of Arkansas tomato growers long after his death. This work was summarized in his Bulletin 194, "Tomato Wilt and Its Control in Arkansas."

At the time of his death Elliott was engaged in a study of the organism causing black rot of the sweetpotato. His careful studies of the evanescent asci of the pathogen led him to the conclusion that the pycnidia of Sphaeronema fimbriata were in reality perithecia and that what had for so many years been considered to be conidia were in reality ascospores. That Elliott's conclusions were sound is attested to by the fact that Ceratostomella fimbriata Elliott is now everywhere recognized as the correct name for the black rot of sweetpotato pathogen.

A year after J. A. Elliott took charge of the Department of Plant Pathology Harry Robert Rosen (B.S., Pennsylvania State College, M.S., University of Wisconsin) joined the staff with the rank of Assistant Professor. During the year 1921-1922, Professor Rosen was on leave of absence at Washington University, St. Louis, where he completed the work for his Ph. D. under Dr. B. M. Duggar.

With service at the Arkansas Station from 1918 up to the present, Dr. Rosen has more than thirty years with the Department, thus exceeding by several years any other member of the Plant Pathology staff.

During this long period Professor Rosen has naturally interested himself in many phases of Plant Pathological research. During the first ten years at Arkansas his titles include two publications on the Bacterial Stalk Rot of Corn, A Bacterial Disease of Foxtail (dissertation for the

doctorate), two bulletins on the Mosaic Diseases of Sweetpotato and one on the Septoria Glume Blotch of Wheat.

During the next few years, Dr. Rosen worked especially on the fireblight disease of apples and pears. Overwintering of the fireblight bacillus in the beehive and the first clearcut explanation of blossom infection through the stomata-like "nectarthodes" of the apple and pear blossoms were among the highly significant contributions to our knowledge of the fireblight disease. Dr. Rosen's work on fireblight was summarized in numerous shorter journal publications and in four extensive bulletins of the Arkansas Agricultural Experiment Station.

Soon after he came to Arkansas, Rosen became interested in the diseases of oats and other cereals and in the possibility of breeding oats for winter hardiness, rust resistance and as a winter pasture crop. Research along this line has resulted in the release of the Traveler variety of oats which has proven its value particularly in the northern part of the winter oat belt because of its high productivity, winter hardiness, and resistance to all common races of the crown rust organism and to common races of loose and covered smut. Several selections of oats, wheat, and barley, primarily bred for disease resistance, are now in the process of development by him.

In addition to the work outlined above, Professor Rosen has been very much interested in the development of new disease-resistant varieties of roses, one of which, Stephen Foster, a hardy climbing rose, has been released to nurserymen for propagation. Improved fungicides for the control of black spot and powdery mildew of roses are another development from this work.

Some months after the death of Dr. J. A. Elliott, which took place in Washington, D. C. where he was for a brief leave of absence with the Plant Disease Survey, the headship of the department was assumed by V. H. Young, Ph. B., Ph. M., Ph. D., University of Wisconsin. Young came from the University of Idaho where he had spent the five previous years as head of the Department of Botany and Plant Pathology.

Professor Young, like his predecessor, has devoted his attention largely to the diseases of cotton and particularly to the Fusarium wilt -- root knot -- potash hunger disease complex. His first publication presented the results of soil temperature studies of the Fusarium wilt disease of cotton. Later studies dealt with soil moisture relationships (with W. H. Tharp) and with the relation of potash deficiency, fertilizer balance, and varietal resistance to the Fusarium wilt disease of cotton. Much of this work was in cooperation with J. O. Ware, George Janssen, and L. M. Humphrey of the Department of Agronomy, and with W. H. Tharp of the Division of Cotton and Other Fiber Crops and Diseases of the U. S. Department of Agriculture. Other phases of the cotton disease problem, especially cotton seedling blights and their control by cottonseed treatment, have been studied more recently. Minor problems have dealt with grape, apple, and strawberry spraying and with cereal seed treatments.

During the year 1921-1922, Raymond F. Crawford, B.S. and M.S. Iowa State, took H. R. Rosen's place while the latter was on leave for graduate studies and in 1928, Dr. Edgar C. Tullis, A.B. and A.M. Nebraska, Ph. D. Michigan State, was added to the staff with the title of Assistant Professor and Assistant Plant Pathologist. Tullis, who was employed jointly by the University of Arkansas and the Division of Cereal Crops and Diseases of the U. S. Department of Agriculture devoted all of his time to rice diseases. In 1930 Dr. Tullis transferred completely to the U. S. Department of Agriculture but continued to carry on his studies of rice diseases in the Department of Plant Pathology until about 1936 when he was transferred to the Rice Branch Station at Beaumont, Texas. During the time that Dr. Tullis was employed by the Arkansas Experiment Station he discovered both the conidial and ascigerous stages of the organism causing stem rot of rice which had previously been assigned to the genus Sclerotium.

Dr. E. M. Cralley, B.S., McKendree, Ph. D., Wisconsin, came to the department in 1931 in a cooperative arrangement with the U. S. Department of Agriculture but shortly was employed full time by the University. For several years, he devoted himself entirely to diseases of rice, but in more recent years he has divided his time between rice disease studies and diseases of alfalfa and soybeans. From December 1946 to February 1948 Dr. Cralley was employed by the U. S. Army to study agricultural problems, especially those connected with rice-growing in Japan and Korea. He returned to the Plant Pathology Department in 1948 with the rank of Professor and Plant Pathologist.

Dr. Cralley was one of the first in this country to demonstrate the value of rice seed treatments for the control of rice seedling diseases and as a result of his work a substantial percentage of the rice sown in Arkansas at present is treated. Control of stem rot of rice through cultural practices, relation of rice fertilization to disease control, the development of rice varieties resistant to disease, and various other rice disease problems have engaged his attention since he came to the Arkansas Station.

Since returning from Korea Dr. Cralley has devoted part of his attention to the "White Tip"

disease of rice. Recently he has shown that this disease is caused by seed-borne nematodes which develop in the terminal bud of the rice plant and produce the typical "white tip" symptoms. Seed treatment studies designed to control this disease are a part of the current rice disease program.

The importance of alfalfa in Arkansas as a crop which is to be processed in dehydrating plants has brought the problem of the longevity of alfalfa plantings to the fore. The failure of alfalfa stands, especially in the Eastern Delta area of Arkansas where the principal dehydrating plants are located, threatens to wipe out a prosperous industry unless these problems are solved. Much of Dr. Cralley's time is now being devoted to this important problem.

Dr. Leslie M. Weetman, A. B. Simpon, M.S. and Ph. D. Iowa State, was a member of the Plant Pathology staff during the period 1936-1942. Dr. Weetman, whose training was largely in Genetics and Plant Breeding, was engaged almost entirely in a cooperative project with Prof. H. R. Rosen designed to develop better disease resistant varieties of oats. This work has been considered previously in connection with the discussion of Dr. Rosen's research. Dr. S. B. Locke, B.S. Oregon State, M.S. and Ph. D. Wisconsin, came to the Department of Plant Pathology in 1939 to initiate a program of vegetable disease research. He was with the Arkansas Station from 1939-1943 and left the department to engage in emergency war work in the U. S. Department of Agriculture. Dr. Locke studied primarily resistance to early blight and Septoria leaf spot of tomatoes and succeeded in securing a number of promising hybrids with South American species of Lycopersicon which showed marked resistance to these diseases. Other crosses which Dr. Locke developed showed promise from the point of view of resistance to the Fusarium wilt of the tomato. Control of tomato leaf spots through use of fungicidal applications was also a part of the tomato disease program upon which he was working.

From 1943-1945 Dr. J. R. Shay, B.S. Arkansas, M.S. and Ph. D. Wisconsin, continued Dr. Locke's work with tomato diseases and also began a study of spinach diseases. One important result of the latter work was a demonstration of the fact that much of what had been called cold weather injury to spinach was in reality "Spinach Blight" caused by one or more strains of the cucumber mosaic virus and that the Old Dominion and Virginia Savoy varieties of spinach possesses a high degree of resistance to several of the strains of this virus. Shay also secured some very interesting preliminary results with the use of eradicant sprays for the control of black rot of grapes.

Dr. Joseph P. Fulton, A.B. Wabash, M.A. and Ph. D. Illinois, succeeded Dr. Shay in 1947. Dr. Fulton has been especially interested in the virus diseases of spinach and other vegetables and in tomato diseases. His discovery of a strain of cucumber mosaic virus capable of attacking blight resistant varieties of spinach in a highly destructive manner demonstrates that the spinach blight problem may become much more severe than it is at present. Recently Dr. Fulton has published the results of his preliminary studies of the spinach virus problem and has with Neil Fulton a report of a tomato root rot caused by the pathogen of buckeye rot of tomato. Dr. Fulton is also studying the virus diseases of strawberries and the red stele disease of strawberries.

Dr. Curtis L. Mason, B.S. and M.S. Texas A. & M. and Ph. D. Illinois, came to the Department with the rank of Assistant Professor and Assistant Pathologist in 1948, Dr. Mason's research at present is very largely confined to a study of bacterial spot and brown rot of peaches and their control by improved spraying techniques. Among the new materials being tried by Mason are calcium and sodium hypochlorite which in preliminary trials reported in 1949 seemed to offer considerable promise for use in the peach spray schedule.

Dr. Albert Miller, B.S., M.S., and Ph. D. Cornell, who was Instructor in Plant Pathology and Entomology from 1938-1940, and Mr. Neil D. Fulton, B.S. Arkansas, who joined the staff in 1949, were hired primarily as members of the teaching staff. Dr. Robert G. Emge, Ph. D. Illinois, was hired as Extension Specialist in Plant Pathology in 1949. Although Dr. Emge is not, strictly speaking, a member of the staff of the Department of Plant Pathology, he continues to interest himself so far as time permits, in research matters, and is already proving his value to our department through his field contacts with practical problems which he encounters throughout the State. Dr. T. C. Liu, Ph. D., Oregon State, a native of China, joined the staff in 1942 and continued for approximately three years as research assistant in connection with studies of the cotton wilt disease.

Besides the members of the Plant Pathology staff enumerated above there have been considerable numbers of graduate and undergraduate students who have gone on to a career in Plant Pathology elsewhere. Some but not all of these men have served either as graduate or undergraduate research assistants in the Department of Plant Pathology. Among those who have either Bachelor's or Master's degrees or both from this institution may be listed the following:

John C. Dunegan, M.S., Arkansas, now Senior Pathologist, U. S. Department of Agriculture
A. B. Groves, M.S., Arkansas, now Plant Pathologist Virginia Experiment Station
John R. Large, M.S., Arkansas, Assistant Plant Pathologist, U. S. Department of Agriculture
Albert L. Smith, M.S., Arkansas, Pathologist, U. S. Department of Agriculture
Luther Shaw, M.S., Arkansas, Agronomist, U. S. Department of Agriculture
A. B. Wiles, M.S., Arkansas, Graduate Student, University of Wisconsin
Ollie D. Burke, B.S.E., Arkansas, Extension Plant Pathologist, Pennsylvania
Glenn S. Pound, B.S., Arkansas, Associate Professor, University of Wisconsi
J. Ralph Shay, B.S., Arkansas, Assistant Professor, Purdue University
George W. Bruehl, B.S., Arkansas, Associate Pathologist, U. S. Department of Agriculture
Mannon Gallegly, B.S., Arkansas, Assistant Professor, University of West Virginia
Harlan Smith, B.S., Arkansas, Graduate Student, University of Wisconsin.
James. G. Horsfall, B.S., Arkansas, Director Connecticut Agricultural Experiment Station

Besides the men listed above, who were either employed by the Arkansas Experiment Station or were students at the University of Arkansas, there should be mentioned three members of the staff of the U. S. Department of Agriculture who were stationed at the University of Arkansas in a cooperative relationship with the Department of Plant Pathology.

Mr. John C. Dunegan, now Senior Pathologist, in charge of Deciduous Fruit Disease Investigations, U. S. Department of Agriculture, Beltsville, Maryland, was stationed with the Department of Plant Pathology from 1928-1945. Mr. Dunegan was concerned primarily with apple spraying investigations but found time to investigate a number of fruit diseases, among which may be mentioned bacterial spot disease of stone fruits and rusts of the genus Prunus.

E. C. Tullis, now Plant Pathologist, Division of Cereal Crops and Diseases, after leaving the staff of the Department of Plant Pathology in 1930 to join the staff of the U. S. Department of Agriculture, was stationed with the Plant Pathology Department for several years and continued his work with diseases of rice.

W. Hardy Tharp, now Senior Physiologist, Division of Cotton and Other Fiber Crops and Diseases, was stationed at the University of Arkansas from 1936-1950 and carried out cooperative studies on cotton diseases with members of the Plant Pathology Staff during part of this time.

ACTIVITIES OTHER THAN RESEARCH

Although these notes are concerned primarily with the research in Plant Pathology, the record would be incomplete without some mention of other activities of the Plant Pathology Staff. These are discussed here briefly.

Extension Work. Except for a very brief period during World War I there was no Extension Plant Pathologist in Arkansas until Dr. Robert G. Emge came here in November 1949. During this time the staff carried out all of the ordinary functions of an Extension Plant Pathologist which need not be enumerated here.

Arkansas State Plant Board. The regulatory work of the State with respect to nursery stock, seeds, fertilizers, feeds, etc. is in charge of the Arkansas State Plant Board of which the head of the Department of Plant Pathology is an ex-officio member. In this capacity he attends all formal meetings of the Board and acts as a consultant in matters pertaining to plant diseases. He does not, however, take part directly in the regulatory activites of the Board. Since 1924 the present head of the department has also served as secretary of the Board.

Teaching Activities. While not all members of the Experiment Station Staff in Plant Pathology have teaching duties, most of them do some teaching and in recent years between 300 and 400 students have enrolled in classes each year in Plant Pathology. The curriculum of the College of Agriculture requires that every graduate in Agriculture complete the introductory course in Plant Pathology and that in addition he take an advanced course in either Plant Pathology or Entomology. Courses are offered in Diseases of Southern Field Crops and in Diseases of Southern Fruit and Vegetable Crops. At least half of the student body elect an advanced course in Plant Pathology. In recent years many students have elected to take both of the advanced courses in Plant Pathology and the corresponding advanced courses in Entomology. Since a very large part of the graduates in the College of Agriculture become either County Agents or Teachers of Agriculture, it is felt that this program, which provides a limited training in the subject for all students rather than a considerable amount of advanced work for a limited group, best serves the interests of the State.

UNIVERSITY OF ARKANSAS, FAYETTEVILLE

PLANT PATHOLOGY IN NEW JERSEY[1]

C. M. Haenseler

INTRODUCTION

New Jersey is relatively small in area, covering only 8,224 square miles, but this smallness does not restrict either the number or the importance of the plant disease problems that occur within its borders. At the southern end of the State there is a warm, humid coastal plain area with an average of 218 frost-free days. At the northern end there are heavier soils with grassy and wooded slopes rising to 1800 feet above sea level. Here the nights are cool and there are, on the average, only 138 frost-free days a year. Such wide variations in season length, soil type, and topography give New Jersey a great variety of growing conditions, which permits the production of a large variety of economic plant types and complicates the problem of economic disease control.

New Jersey has extensive areas devoted to special crops such as cranberries and blueberries which present disease problems not met with in many other States. Our proximity to large metropolitan centers also adds materially to the plant pathologists' troubles. These nearby markets have encouraged development of numerous intensive truck garden centers with many acres under glass. These truck areas alone grow some half hundred different types of miscellaneous vegetable crops. Other sections, specializing in canning crops, grow many thousands of acres of tomatoes, asparagus, peas, beans, peppers, and spinach. Extensive muck lands, devoted largely to onions, celery, and lettuce, create disease problems peculiar to this particular soil type and cropping system. Tree fruits, both apples and peaches, with their multiplicity of diseases, cover some 39,000 acres. Small fruits, such as raspberries, blackberries, and strawberries, also find their place but on a much smaller scale.

New Jersey has some of the largest nurseries in the country as well as many large greenhouse establishments specializing in roses, orchids, ferns, or miscellaneous ornamentals for the metropolitan trade. This immense field of ornamentals alone presents a long list of disease problems that constantly calls for study and service.

Obviously, large urban centers such as we have in and adjacent to New Jersey mean large investments and consequently intense interest in shade trees, lawns, golf links, public parks, water sheds, and private gardens. All of these add tremendously to the plant disease problems and to the demands that are made upon the plant pathologist.

Forage and grain crops demand attention in the larger dairy centers where the soil type or topography is adapted to a pasture-hay-grain farming system rather than to cultivated crops.

Not only has New Jersey this immense variety of economic plants, which multiply the number of disease problems; her climate also adds to the trouble. Rainfall is usually abundant and often erratic, and even when rainfall is below normal there may be long periods of high humidity and heavy dews or fogs. These conditions frequently bring on severe outbreaks of diseases and make control more urgent and more difficult.

This combination of a great variety of economic plants, grown both intensively and extensively, along with a climate that is highly conducive to the development of various plant diseases, makes New Jersey a fertile field for the development of plant pathology. It would be expected, therefore, that plant pathology, both as a technical science and as a practical aid to solving plant disease problems, should have developed at a very early date in New Jersey.

DR. HALSTED--PIONEER PLANT PATHOLOGIST

Plant Pathology had its birth in New Jersey with the appointment of Byron D. Halsted as botanist in the New Jersey Agricultural College Experiment Station in 1889. Dr. Halsted was trained as a botanist, but his major interest for many years lay in the field of plant diseases. He was deeply interested in the applied side of botany, as is evident from the fact that some dozen of his earliest publications dealt with plant pathogens.

It must have been a welcome challenge for this pioneer plant pathologist when he was appointed to a position in New Jersey where plant disease problems were so numerous, so varied and of such economic importance. We see this reflected in Halsted's report written after his first summer in New Jersey: "The season just closed (1889) has been a remarkable one for the ravages

[1]Paper of the Journal Series, New Jersey Agricultural Experiment Station, Rutgers University - The State University of New Jersey, Department of Plant Pathology.

of injurious fungi. All crops have suffered and some, especially those of fruits have been almost a failure." These heavy crop losses due to plant diseases and lack of information on methods of preventing them must have had a great deal to do with Dr. Halsted's decision to enter the field of plant pathology so seriously.

The challenge to prevent these "ravages of injurious fungi" was accepted immediately, and for many years Dr. Halsted devoted most of his time and thoughts to the study of plant diseases. His greatest ambition was to solve the plant disease problems that were causing such severe losses in those early days when plant pathology was in its infancy.

During 1889 Halsted studied such destructive diseases as late blight rot of potatoes, black rot of grapes, leaf gall and fruit rot of cranberries, downy mildew of cucumber and rots of the sweetpotato. Disease control with fungicides was carefully studied and the use of bordeaux mixture was advocated for the control of various diseases. In subsequent years the field was gradually expanded to include a wide variety of crops such as miscellaneous vegetables, small fruits, tree fruits and a long list of ornamentals. These studies were so extensive that as many as thirty or forty different economic plant diseases were studied and reported upon in a single season. Nor were these studies superficial in many cases. For example, the club root disease of cruciferous crops, soil rot of sweet potatoes, common scab of white potatoes, fire blight of pears rust of asparagus, and numerous other diseases were carefully studied year after year, from the standpoints of etiology and of control. Many contributions of permanent value resulted from these early studies.

During the years that Dr. Halsted devoted his major attention to plant pathology a number of new diseases were discovered, studied, and accurately described, and the life histories of several important pathogenic fungi were investigated. Many of the better known diseases that were causing serious crop losses at the time were also studied in detail and control measures suggested. Numerous cross inoculations were made, particularly with Gloeosporium, to determine differences or similarities among several so-called species attacking various hosts. Many of these studies were of the utmost importance in leading the way toward later developments in the field of plant pathology.

With all of these detailed studies Dr. Halsted never lost sight of the ultimate aim of the plant pathologist: disease control. The effectiveness of copper fungicides, especially bordeaux mixture, in controlling numerous foliage diseases was tested repeatedly, and lime applications made to the soil were found to prevent club root of cabbage. He demonstrated that sulfur applied to the soil would reduce the losses from both scab in white potatoes and soil rot in sweetpotatoes. The value of seed treatments was also investigated, and certain treatments were advocated for cereals and other crops.

HALSTED RETURNS TO BOTANICAL STUDIES

It was a serious blow to plant pathology, and it must have been to Dr. Halsted himself, when failing eyesight finally forced him to give up the tedious microscopic studies that he so dearly loved and that he considered so essential to the progress of plant pathology in those pioneer days. He found other useful outlets for his boundless energies, however, and devoted his last years largely to studies in genetics and plant breeding. This transfer of interest from plant diseases to breeding began in 1898, and by 1900 most of Dr. Halsted's time was devoted to his new projects.

During the short period from 1889 to 1899, which Dr. Halsted devoted almost exclusively to pioneering work on plant diseases, he laid a foundation for plant pathology that was both extensive and solid. In Dr. Halsted, plant pathology had a far-sighted and energetic pioneer who not only blazed a clear trail but also opened many roads that led to practical plant disease control.

DEPARTMENT OF PLANT PATHOLOGY FORMED

This early work in plant pathology was a very firm footing upon which to build a special Department of Plant Pathology in New Jersey. This new Department was established in 1911, and Dr. Melville T. Cook, a graduate of Stanford University and holder of advanced degrees from De Pauw and Ohio State Universities, was appointed as New Jersey's first plant pathologist to head it. Dr. Cook was also appointed New Jersey State Pathologist, in charge of nursery inspection under the State Board of Agriculture.

The new Department of Plant Pathology under Dr. Cook's leadership grew rapidly and two assistants were appointed within the year. The destructive chestnut blight disease (Endothia parasitica) was at its height during these years, and Dr. Cook devoted much time to a detailed study of this dreaded disease. The virus diseases, yellows and little peach, which were threatening

New Jersey's important peach industry were included in the research program. Dr. Cook and his associates also continued the investigation on sweetpotato diseases, apple storage rots, and diseases of ornamental plants which had been started by Dr. Halsted.

During this period Carl A. Schwarze, who devoted his major time to nursery inspection, performed a lasting service to all future New Jersey plant pathologists by his monumental work of recording by careful descriptions and detailed pen drawings, some 350 parasitic fungi commonly found on economic plants in New Jersey.

Dr. Cook remained head of the Department of Plant Pathology from 1911 until 1923, when he resigned to become plant pathologist of the Insular Experiment Station at Rio Piedras, Puerto Rico. During these first twelve years, the Department had grown slowly but steadily, so that by the time Dr. Cook resigned it consisted of four full-time plant pathologists and several graduate assistants.

DR. WM. H. MARTIN BEGINS HIS LONG CAREER AS HEAD OF PLANT PATHOLOGY

With this staff as a nucleus Dr. Wm. H. Martin, who was appointed head of the Department to succeed Dr. Cook, further expanded the plant disease research program and gradually added three more members to the staff. It now includes seven full-time plant pathologists in addition to a fluctuating number of graduate assistants.

Under Dr. Martin's leadership the work of the Department was distributed among the staff members largely on a crop basis. From this time on, the plant pathology Department developed along specific crop lines with specialists in each field. Further discussion of this development will deal with crops rather than chronological events.

EXTENSIVE WORK ON POTATOES

Dr. Martin had served as potato specialist for several years under Dr. Cook. Before being appointed head of the Department, he had already made marked progress in the study of the numerous and perplexing disease problems affecting New Jersey's multimillion dollar potato crop. As head of the Department, Dr. Martin continued and even expanded this extensive research program on potatoes. First Graham Campbell and later John C. Campbell took charge of all the potato work under Dr. Martin's personal supervision.

A unique departure from the usual departmental duties was undertaken in connection with this potato program. Dr. Martin had originally been assigned to conduct all work on the white potato, regardless of whether it pertained to diseases or whether it was related in some other way to economic potato production. This arrangement permitted the development of an all-inclusive potato research program able to cope with any problem that seriously affected the potato industry.

In the earlier phases of these potato studies disease problems were of paramount importance. Scab was reducing yields and seriously impairing quality. Rhizoctonia was causing irregular stands and affecting both yields and salability of the crop. Late blight took very heavy tolls under certain conditions, and the foliage breakdown, popularly called "hopper burn", was a serious problem. In addition to these, several virus diseases were causing more and more trouble in the production of white potatoes for seed and threatened to destroy this particular industry.

One after another these troubles were eliminated as serious threats to the potato industry. In line with suggestions made by Halsted in his pioneering work, sulfur as a scab control agent was more carefully investigated and soon was successfully used to eliminate this disease as a major problem. Later by coordination of the fertilizer and disease studies it was found that the proper use of physiological acid fertilizers which tend to reduce the pH of the soil gave perfect control of scab. This simple method eliminated the need for special sulfur applications and avoided some of the objectionable features of the former method.

Years of work on Rhizoctonia have greatly reduced the losses caused by this disease. Experiments by the hundreds have been conducted during the last 25 years to determine the relative effectiveness of fungicides in controlling late blight and other foliage diseases. These have included comparative studies with numerous fungicide-insecticide combinations; comparison of dusts with sprays; studies on the relative value of calcium and magnesium limes when used in sprays or dusts; careful study of substitutes for bordeaux mixtures and of various organic fungicides; and numerous other studies related to spraying and dusting. As new insecticides were introduced or suggested as possible substitutes for the standard types in use at the time, these were included in the extensive field experiments.

Numerous laboratory, greenhouse and field experiments were conducted along nutritional lines. Studies were included on highly concentrated and other fertilizer types, plant food sources, minor elements, fertilizer placement and rates of application.

Experiments on depth of planting, seed-piece spacing, seed-piece size and varieties were included to determine under what condition highest yields might be obtained. Crop rotation systems, cover crops, and irrigation studies were added to this all-inclusive potato program.

In addition to directing these careful studies on potato problems that affect the New Jersey grower, Dr. Martin has led numerous national potato programs of importance. He worked hard and successfully to improve the potato seed certification program and to encourage the use of only certified seed by every grower. He has also aided the general potato industry by his long and efficient service as editor of the American Potato Journal. He may be given credit largely for the development of orderly marketing programs to prevent sharp breaks in prices during the peak of the harvesting season.

As a result of these years of coordinated research on diseases as well as production and marketing problems all cemented into a well-integrated general potato program, diseases and numerous other problems that formerly threatened the potato industry of New Jersey have been greatly minimized or eliminated entirely.

CONTROL OF FRUIT DISEASES

New Jersey's 35,000- to 40,000-acre apple and peach industry has received invaluable aid as a result of many years of continuous study of the numerous disease problems affecting these crops. Here the Department of Plant Pathology limited its studies largely to pathological problems, although nutritional studies have been included where these were associated with the incidence or with the symptom expression of the disease.

These orchard studies were started in the early 90's by Dr. Halsted. Around the turn of the century, fire blight of pears became a serious problem. Pruning tests were found to give some degree of control, but the twig blight phase of the disease was never wholly subdued.

When lime-free fungicides were introduced, another new problem arose on peaches. This trouble, which resembled a canker disease, was carefully studied and found to be a result of arsenical injury. Losses from this source were largely eliminated by 1925, although further studies on arsenical injury were conducted more recently by Dr. Robert H. Daines.

The economic importance of the fruit industry in New Jersey forced the plant pathology Department to conduct research on orchard diseases annually since Halsted's early work, but it was not until the appointment of Dr. Daines to the staff in 1930 that tree fruits received the attention they deserve. Dr. Daines has devoted a large part of his time to careful studies on the most effective means of controlling scab, fruit spot, black rot, bitter rot, cedar rust and fire blight of apples. Similar attention has been given to leaf spot of cherries and to brown rot, bacterial spot and canker diseases of the peach. As a result of these studies the most progressive orchardists are now growing fruit crops virtually free from major diseases and are able to compete with other fruit areas where disease problems are not so acute.

This very active fruit research program is still in progress, testing the various new fungicides as they appear and looking forward to continuous improvement of the costly spray and dust schedules necessary to produce a salable crop. Careful studies are also continuing on bacterial spot of peach and other diseases that have not yet fully surrendered to our control measures.

SWEETPOTATO DISEASES IMPORTANT IN NEW JERSEY

In addition to this fruit disease program, Dr. Daines has made notable contributions toward the solution of serious disease problems in sweetpotatoes. Sweetpotatoes have always been a very important crop in New Jersey, and losses from diseases are normally very heavy. Studies on this crop were started in 1889 by Dr. Halsted, and some progress in disease control was made in those early days. Dr. Cook himself continued the sweetpotato disease studies on a minor scale for a number of years until they were expanded into a major study by Dr. R. F. Poole from 1920 to 1926. Dr. Poole devoted the greater part of his time to this crop and made excellent progress before he resigned in 1926. After Dr. Poole's resignation the momentum of the sweetpotato studies was decreased for a time, but the most important projects were continued during the interim by Dr. Martin and various members of the staff. They were ultimately taken up as a major project again by Dr. Daines when Martin's administrative duties forced him to transfer some of his research projects to other members of the staff.

Under Dr. Daines, the sweetpotato work was further expanded to include several problems not studied in detail before. He continued the study on such sweetpotato field diseases as pox, stem rot, and scurf started by his predecessors, and in addition made extensive studies of plant-bed diseases and sprout-borne diseases, as well as storage and transit rots. Marked progress

has been made in the control of plantbed troubles; successful sprout dips have been developed which largely eliminate sprout-borne diseases; and outstanding results have been obtained in the control of sweetpotato rots that have caused heavy losses during the storage and marketing periods.

A borax dip was developed which greatly reduced the losses from decay during marketing. Even greater benefits have resulted from studies on storage methods. Years of study with a dozen experimental storage chambers, with both temperature and humidity controls, have resulted in specifications for commercial storages that are reducing rot and shrinkage to a minimum. The full effects of these studies will be felt more keenly as time goes on and as more storages are constructed according to these new specifications.

The benefits derived from the long years of studies that have been conducted on sweetpotato diseases alone have added millions of dollars to the economy of New Jersey's agriculture.

ORNAMENTALS HAVE RECEIVED MAJOR ATTENTION

The development of the ornamental branch within the Department of Plant Pathology in New Jersey has been epoch-making. New Jersey's immense investment in ornamental plants and the many plant diseases that threaten these investments have caused continuous pressure on plant pathologists for more and more information on how best to protect lawns, shade trees, greenhouse and nursery stock and other ornamentals from losses due to diseases. Dr. Halsted keenly felt this pressure as soon as he arrived in New Jersey and did a great deal of work on diseases of ornamentals in the early nineties. Dr. Cook continued these studies in a minor way, and various other members of the plant pathology Department were delegated from time to time to investigate problems of immediate importance. These earlier studies were of an emergency nature, however, and were never developed to the extent that the investment in ornamentals warranted.

The need for expanding the research program on ornamentals finally became so urgent that in 1927 Dr. R. P. White was appointed to devote his entire time to the study of disease problems of ornamental plants. Dr. White continued these studies for eleven years, until he resigned to become executive secretary of the National Association of Nurserymen. During those years Dr. White worked on a variety of disease problems affecting ornamental plants, including roses, gladioli, ericaceous plants and many others.

Dr. P. P. Pirone took over the study of ornamentals where Dr. White left off also devoting his entire time to this field. He continued investigation of a long list of nursery, florist, shade tree and lawn problems until 1947, when his wide experience drew him to the New York Botanical Garden staff. After a short lapse of time enforced by the scarcity of men trained in pathology of ornamental plants, disease work in this special field in New Jersey was taken over by Dr. Spencer H. Davis, Jr. in 1948. Dr. Davis devotes full time to this large and important group of plants, as did his two predecessors.

VEGETABLE DISEASES IMPORTANT IN THE GARDEN STATE

Vegetable production is another very significant branch of agriculture in New Jersey. The development of an extensive research program for this large group of plants is to be expected in a State that boasts the title of "The Garden State." Some half-hundred vegetable crops are grown commercially in New Jersey, and each is attacked by one, or sometimes a half dozen or more, diseases of considerable importance.

The vegetable disease studies, like so many others, were begun in 1889 by Dr. Halsted. They have been carried on without interruption since that time. From 1922 to the present time these studies have been made largely by Dr. C. M. Haenseler, assisted in recent years by Dr. B. H. Davis. Because of the large number of vegetable problems calling for attention in New Jersey, most of the efforts have been directed toward development and improvement of control measures. Less attention has been given to technical studies on etiology and to detailed studies of life histories or physiology of the pathogens. Careful attention has been given to such important diseases as anthracnose, early blight and late blight of tomatoes; mosaic and bacterial leaf blight of peppers; root rot of peas; club root of crucifers; wilt and fruit rot of eggplants.

Virus yellows of lettuce and bacterial wilt and smut of sweet corn have also received careful attention.

In cooperation with the entomology department, a satisfactory control measure for lettuce yellows was developed and its was also found that ear smut of sweet corn, which sometimes destroys 30 to 60 percent of the ears of certain varieties, could be greatly reduced or almost eliminated in some cases by the use of certain insecticidal dusts.

Studies have been conducted on problems that affect vegetable crops in general, such as seed decay, damping-off of seedlings, miscellaneous plantbed diseases and root knot nematodes.

In addition to these major studies, numerous other disease problems which occur only spasmodically have been added to the vegetable disease research program from time to time. A few outstanding examples of such spasmodic outbreaks of diseases which cause little trouble in the average season are as follows: asparagus rust in 1896-97 and again in 1924 and 1936; bacterial wilt of sweet corn from 1928 to 1933 inclusive; bean rust 1936-38; and late blight of tomatoes 1946-48. In each of these periods special emergency studies were conducted on the specific diseases.

A detailed survey of the vegetable disease studies conducted in New Jersey alone since 1889 would give a graphic picture of how numerous, how varied and how important phytopathological problems can become in a small area.

CRANBERRY AND BLUEBERRY DISEASE STUDIES

Plant disease studies on cranberries and blueberries in New Jersey developed somewhat independently of the Plant Pathology Department, yet these projects are of such importance that they deserve to be recorded here. Since the beginning of the studies on cranberry and blueberry diseases, the major part of the work has been done at a branch station at Pemberton in the vicinity of bog areas. The extensive disease studies at the Cranberry-Blueberry Station were conducted almost in their entirety by the late R. B. Wilcox, who was assigned by the U. S. Department of Agriculture to cranberry and blueberry work in New Jersey. Wilcox did monumental work on control of false blossom and fruit rots of cranberry and on the virus "stunt" and other diseases of the high bush blueberry. The false blossom virus disease of cranberries might have doomed this crop had it not been for the study of the vector and the consequent development of control measures by Wilcox. His great progress in breeding cranberry varieties resistant to false blossom is also noteworthy. This work will bear fruit for many years to come.

AIR POLLUTION WITH PHYTOTOXIC FUMES

In addition to the disease problems that receive attention year after year, emergency cases occasionally arise which demand prompt and careful investigation by the pathologists. Some of these become perennial problems also and are added to the regular studies. Such a problem arose some years ago when phytotoxic industrial fumes were released in damaging quantities in the vicinity of New Jersey's important agricultural areas. Demands for information on the cause and extent of these injuries and for corrective measures brought a new line of research to the plant pathology Department. It was soon found that fluorine was most probably the menacing chemical. Since little information was available on the subject, a special fundamental research program was developed to obtain information on all phases of the fluorine plant-injury problem. Dr. Daines was placed in charge of this project, and several chemists and members of other departments have assisted in various phases of the work.

These studies on fluorine recently aided farmers greatly in obtaining reimbursements for damages caused to their crops by fluorine gases. They have also been instrumental in hastening the installation of industrial safeguards which should greatly reduce the danger of crop loss from similar sources in the future.

DEVELOPMENT OF NEW FUNGICIDES

Another significant chapter in the history of plant pathology in New Jersey deals with the development of new fungicides. A great deal of attention has been given by every member of the department to the evaluation of various new experimental and proprietary fungicides as they have been proposed or placed on the market. Such studies are necessarily conducted on each important crop and in every major climatic area before definite recommendations can be given. In addition to this herculean task of evaluation of known fungicides and of determining where and how each can best be used in practical plant disease control, the Department of Plant Pathology has played an important role in the development of new fungicides.

The first far-reaching step in this field was made in 1915 when Prof. A. J. Farley began trials with lime-sulfur-glue mixtures as substitutes for self-boiled lime sulfur, the spray material commonly used on peaches at that time. After further improvement and modification of these lime-sulfur-glue mixtures, Prof. Farley, in 1923, introduced "New Jersey dry mix" a simple formulation containing sulfur, lime and calcium caseinate. This mixture could be mixed dry, stored in bags and added directly to water to make an effective, easily applied fungicide for use on

peaches and other stone fruits.

The introduction of "New Jersey dry mix," the first of the so-called "wettable sulfurs," was followed by various other types of "wettable sulfurs" which have totally replaced the original self-boiled lime sulfur so popular before 1923.

The next big step taken by New Jersey in developing new fungicides was Dr. Alwyn Sessions' introduction of "Coposil." This copper silicate fungicide was developed in the Department of Plant Pathology from 1929 to 1933 in response to the current need for a copper fungicide that was miscible with oils and safe to use on pomaceous fruits. "Coposil" was the first copper fungicide developed since the discovery of bordeaux mixture between 1882 and 1885 that has been used on a large scale. The introduction of "Coposil" seems to have been the spark that touched off a series of research studies which finally resulted in the development of such fungicides as the copper oxides, basic copper sulfates, copper oxychlorides, and copper oxychloride sulfates.

In recent years the Department of Plant Pathology has continued its interest in new fungicides. It has biologically "screened" hundreds of chemicals in search for compounds with outstanding fungicidal properties and low phytotoxicity.

This tedious search has yielded a new product with high toxicity to fungi and low toxicity to higher plants and animals. This recent development, announced late in 1949 under the laboratory number SR 406, has given marked success in the control of many plant diseases both in America and abroad. It may prove to be the third notable forward step made by New Jersey in the steady march toward new and better fungicides.

EXTENSION IN PLANT PATHOLOGY

In the field of agricultural extension, plant pathology in New Jersey has developed along somewhat hybrid lines. No extension specialist in plant pathology has ever been appointed in the State, although this does not mean that plant pathology has not received due attention by the extension division.

Through his 40 years of contact with fruit disease problems in New Jersey, Prof. A. J. Farley, extension specialist in horticulture, has become an expert practical fruit pathologist. He has devoted the major part of his thought and time to problems confronting New Jersey's apple and peach industry and has been largely responsible for the effective job New Jersey fruit growers are doing in producing disease-free fruits. It is largely due to Prof. Farley's long years of contact with the fruit growers and his thorough understanding of fruit disease problems that the New Jersey grower is so well informed on the major diseases and the latest methods of control.

Charles Nissley has followed a similar course as extension specialist in vegetable production during the 32 years that he has held this position. Since diseases have always caused serious losses in vegetable crops in New Jersey, it has been imperative that the extension specialist give disease control a prominent place in each year's program, and Nissley's long contact with vegetable problems has given him a thorough knowledge of the many diseases of vegetable and truck crops that occur in the State.

Excellent work in the practical solution of disease problems affecting small fruits and vine crops, especially strawberries, raspberries, and grapes is also being done by Ernest Christ, the extension specialist in pomology. All this work is conducted in the closest cooperation with specialists in plant pathology.

In addition to these crop specialists in the extension division who have been distributing information on plant diseases to New Jersey growers for so many years, there was appointed in 1949 an extension specialist in entomology, the first such appointment in the State. Although his official title is extension entomologist, this specialist is devoting some of his time to plant disease problems.

CLOSE COOPERATION AMONG PLANT PATHOLOGISTS AND OTHER SPECIALISTS

The lack of an extension specialist in plant pathology in New Jersey who devotes full time to disease control has been a handicap in some respects, yet it has had its beneficial effects also. It has forced the various research plant pathologists to allocate portions of their time to duties of an extension nature. Under this system, the extension phases of plant pathology have not suffered so much as might be expected. And in many ways it has proved advantageous in that it has kept the research pathologists in intimate contact with the practical disease problems that were most urgently in need of solution at the time. This has had a tendency to focus most of the plant disease research program on applied phases of the science rather than on more fundamental technical problems.

There is another phase of the plant disease work in New Jersey that has developed as a direct result of the lack of a large staff of plant pathologists. Since such a small research staff is unable to cope with all of the important plant disease problems that need attention, many cooperative projects have been pursued with other departments interested in problems in which plant diseases play an important role.

Some very important results have been obtained through these cooperative efforts. As examples we may point to the improvement of varieties through breeding and to the development of improved methods of turf disease control. Breeding programs conducted by the Vegetable Crops Department have resulted in such successful varieties as the world famous Rutgers tomato and the mosaic-tolerant World Beater #13 pepper.

The successful breeding program conducted on fruits by the Horticultural Department has likewise resulted in the introduction of numerous noted varieties of peaches as well as several varieties of strawberries that are virtually immune from the red stele disease. These breeding programs received close cooperation from plant pathologists in developing the degree of disease tolerances that these varieties possess.

Cereals and field crops have received little attention from disease specialists in New Jersey. But here also many research projects on small grain, corn, and hay crops have included disease studies through cooperation between the plant pathologists and the field crop specialists in charge of the work. Breeding work on alfalfa with resistance to bacterial wilt as one of the major objectives, and the development of hybrid corn, with resistance to stalk rot in field corn and to bacterial wilt in sweet corn as important factors, are examples. Success in these projects has been aided materially by the cooperation of trained plant pathologists.

With this intricate relationship between plant pathology and various other branches of agricultural research, the influence exerted by the plant pathologists in New Jersey has reached far beyond the specific major research studies conducted by the pathologists themselves. Much has been accomplished by this whole-hearted cooperative spirit that permeates the Plant Pathology Department. The Department's policy has always been to help in every way possible where plant disease problems are involved.

THE STATE DEPARTMENT OF AGRICULTURE: ITS ROLE IN PLANT PATHOLOGY

A discussion of the development of plant pathology in New Jersey would not be complete without some mention of the important role played by the State Department of Agriculture. The State Department is responsible for the regulatory work pertaining to plant diseases and for such eradication measures as may be required from time to time. It is also in charge of seed certification and nursery inspection, programs that have tremendous effects on the disease problems of specific crops.

SEED CERTIFICATION BY STATE DEPARTMENT OF AGRICULTURE

Freedom from seed-borne diseases is a major item in the specifications for seed certification. Where seed-borne diseases are an important factor in economic crop production an effective seed certification program has far-reaching results in disease control. The importance of the seed certification program in New Jersey is illustrated by the volume of tomato seed production alone. The 10-year average production of New Jersey certified tomato seed from 1939-48 was approximately 76 tons annually. An all-time high was reached in 1947 when more than 146 tons of certified tomato seed was produced. This is an immense volume for a crop that takes so little seed to plant an acre. It is easy to conceive what could happen if this huge quantity of seed, which is sold all over the world, lacked the protection against seed-borne diseases that is provided by certification.

Barley, soybeans, corn, and potatoes intended for seed also come under the careful scrutiny of the State Department's seed certification program. In these crops the grower is provided with a source of seed that should give the minimum hazard from diseases due to seed-borne pathogens.

QUARANTINES AND DISEASE ERADICATION BY STATE DEPARTMENT

The State Department is charged with the duty of enforcing quarantines that restrict the movement of specific diseased material considered dangerous from standpoint of plant disease control. It may also be called upon to eradicate newly introduced diseases as it was when the Dutch elm disease threatened to destroy the American Elm. In this case a very extensive program, conducted in cooperation with the Federal government, was undertaken in a desperate effort to eradicate this destructive disease while it was still confined to a relatively small area. Many thousands of

infected elm trees were destroyed in an attempt to exterminate the causal fungus or effectively to reduce the population of the insects that transmit the disease. Although these attempts were not wholly successful, similar alertness and enthusiasm on the part of the State Department in the early eradication of some other newly introduced diseases may pay untold dividends.

It is worthy of record that all phases of plant disease work done by the State Department of Agriculture is undertaken after consultation with plant pathologists at the State University and Agricultural Experiment Station. This close cooperation among regulatory agencies and the research specialists has been a great help in establishing and maintaining a uniform plant disease control policy in the State. All branches of the State that deal with plant disease problems, whether they relate to research, extension, formal education, or regulatory work, have the same general viewpoint and work in harmony toward a common goal.

TEACHING IN PLANT PATHOLOGY

A final branch of plant pathology as it has developed in New Jersey deals with formal training of students in the subject of plant diseases and methods of control. The Department of Plant Pathology at Rutgers University has taught formal courses in plant diseases for more than a third of a century. During the first few years of this period, only undergraduate courses were available to the student. Later, advanced studies leading to the degrees of Master of Science and Doctor of Philosophy, with majors in plant pathology, have been offered.

Every college student majoring in fruit or vegetable production is required to take a fundamental course in plant pathology. More advanced courses are available for those undergraduates who need more specialized training in this field. Further specialization both in class and research is available for students desiring to enter the field of plant pathology as a profession.

In addition to this fundamental and detailed training in plant pathology given to full-time college students, Rutgers University also offers numerous types of "Short Courses" in plant diseases to special groups. These vary from 3- to 5-day intensive courses on plant disease problems for groups with highly specialized interests, to 10- or 12-week formal "Short Courses in Agriculture" for adult students who wish to study agricultural problems in general.

These various courses in plant pathology, given to both full-time and part-time students in Rutgers University annually, have had a far reaching effect on the gross plant pathology picture in New Jersey. Many of the leading farmers have had brief but intensive formal training in plant diseases. They are therefore well equipped to function as effective agencies for distribution of reliable information on plant disease control within their community. Most of New Jersey's county agricultural agents, vocational agricultural school teachers, club agents and other leaders who come into intimate contact with farmer groups have received more or less detailed instruction in plant diseases and plant disease control. True, these various leaders are far from professional plant pathologists, but they do have a sufficiently broad training to act as reliable agents for dissemination of the latest information on plant disease control.

The benefits derived from this widely scattered group of community leaders who have had some training in plant pathology is more and more obvious as the years go by. Improvement is not always evident from one year to the next, but from decade to decade, or even shorter intervals, marked advancement can be seen. As a result of this gradual improvement, the average New Jersey farmer today approaches his plant disease problems with a much better understanding of the principles involved in disease control, and therefore with better assurance of success, than ever before.

We may attribute this improvement largely to the persistent educational work done by extension agents and local leaders familiar with the general aspects of plant pathology. And we may in turn attribute the success of these workers largely to the formal training in plant pathology that they themselves received at the university.

PLANT DISEASE SURVEY

One of the weakest links in New Jersey's plant disease program is in recording the occurrence and relative importance of plant diseases. Through the diligent efforts of Dr. Elizabeth S. Clark, Assistant Plant Pathologist, the department has fairly complete records for over 20 years of all plant diseases sent in for identification or reported by various other members of the department. These records are of the greatest value but they are not sufficiently complete to reflect the true significance of the various diseases.

There has been no careful survey for the specific purpose of recording all plant diseases that occur within the State and consequently many of the minor diseases still remain unreported from

New Jersey in official lists giving disease range.

The research, teaching and extension staffs have been so occupied in assembling and distributing urgently needed information on the major disease problems that the project on disease survey has been somewhat neglected. A more elaborate program of estimating crop losses caused by diseases and of recording the presence and prevalence of diseases annually is greatly needed. The addition of a strong and well-planned disease survey to the other branches of plant pathology in New Jersey would round out the program so that it should be well-equipped to deal with all the major disease problems occurring within the State.

MORE WORK YET TO BE DONE

This long-uninterrupted growth of plant pathology in New Jersey, from 1889 to the present, impresses us with the truth of Dr. Halsted's original contention that plant diseases in New Jersey are major items in economic crop production and that they deserve the most careful study. Since Dr. Halsted's pioneering days, many of the serious diseases have yielded, either partly or completely, to the advancing science of plant pathology. Much has been done in the past, but much remains to be done in the future.

The battle of plant pathology is by no means over. The need still exists for more effective and more economical control measures for most of our common diseases; there are ever-increasing demands for varieties resistant to specific diseases; and there is a crying need for more practical methods of controlling virus diseases, which are becoming more and more troublesome. New disease problems are sure to rise from time to time in the future. They have done so in the past and we have every reason to believe that they will continue to increase both in kind and importance in the years ahead.

New Jersey looks upon her past development of plant pathology with due pride, but she is ready to admit that serious disease problems still exist and that even more serious troubles may be lurking in the future. She plans, therefore, to continue the steady march forward in plant disease studies, building further on the broad base that has proved so firm in the past, that is, research, extension, teaching, and regulatory activities, all working in close cooperation and directing their efforts toward a common goal -- the most economic control of plant diseases.

DEPARTMENT OF PLANT PATHOLOGY, RUTGERS UNIVERSITY, NEW BRUNSWICK, NEW JERSEY

THE PLANT DISEASE REPORTER

Issued By

THE PLANT DISEASE SURVEY

Division of Mycology and Disease Survey
BUREAU OF PLANT INDUSTRY, SOILS, AND AGRICULTURAL ENGINEERING
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UNITED STATES DEPARTMENT OF AGRICULTURE

SUPPLEMENT 196

AN INDEX OF THE PLANT RUSTS RECORDED FOR CONTINENTAL CHINA AND MANCHURIA

Supplement 196 November 15, 1950

The Plant Disease Reporter is issued as a service to plant pathologists throughout the United States. It contains reports, summaries, observations, and comments submitted voluntarily by qualified observers. These reports often are in the form of suggestions, queries, and opinions, frequently purely tentative, offered for consideration or discussion rather than as matters of established fact. In accepting and publishing this material the Division of Mycology and Disease Survey serves merely as an informational clearing house. It does not assume responsibility for the subject matter.

PLANT DISEASE REPORTER SUPPLEMENT

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THE PLANT DISEASE SURVEY
DIVISION OF MYCOLOGY AND DISEASE SURVEY

Plant Industry Station Beltsville, Maryland

AN INDEX OF THE PLANT RUSTS RECORDED FOR CONTINENTAL CHINA AND MANCHURIA[1]

George B. Cummins[2] and Lee Ling[3]

Plant Disease Reporter
Supplement 196 November 15, 1950

This index was initiated as an aid to the identification of a collection of Chinese rusts (Cummins, 3, 4, 5). Midway in the project the junior author became interested and it was decided to publish the index in its present form. It is our belief that the index is as complete as is reasonably possible. Inasmuch as only a relatively few Chinese collections have been available for study it has not been possible to critically annotate any appreciable number of species. The index should be accepted, thus, primarily as a compilation of published records.

As arranged the species of rusts and of hosts are integrated into a single index. All names of rusts are underlined, wherever they occur, while the names of hosts are not. Citations to literature are entered only after the hosts of specific rusts as: Aecidium akebiae P. Henn.: Akebia quinata (1, 23, 35, 38, 44). It is possible, as the index is organized, to ascertain what species of rusts occur on any particular host or to find all hosts reported for any species of rust.

Since Tai's "A list of fungi hitherto known from China" served as the basis of this index his paper has been retained, for convenience, as reference number 1 and papers cited by him are not indicated individually. However, to make the literature record more complete all papers cited by Tai are appended in a separate list. Reference numbers 2 to 45 refer to papers either published subsequent to Tai's "List" or overlooked by him.

ABIES (Pinaceae) forrestii Craib.: Melampsorella caryophyllacearum.
ABRUS (Leguminosae) mollis Hance: Ravenelia ornata.
ABUTILON (Malvaceae) avicennae Gaertn., see Abutilon theophrasti.
Abutilon theophrasti Medic: Puccinia heterospora.
Abutilon gebauerianum Hand.-Mazz.: Puccinia abutili.
Abutilon sp.: Puccinia heterospora.
ACACIA (Leguminosae) confusa Merr.: Poliotelium hyalospora.
ACANTHOPANAX (Araliaceae) spinosa Miq.: Aecidium acanthopanicis.
ACHYRANTHES (Amaranthaceae) aspera L.: Uredo verecunda.
ACONITUM (Ranunculaceae) delavayi Fr.: Uromyces aconiti.
Aconitum fischeri Reich.: Puccinia lycoctoni.
Aconitum volubile Pall.: Puccinia rubigo-vera.
Aconitum vilmorinianum Franch.: Coleosporium aconiti.
ACORUS (Araceae) calamus L.: Uromyces pyriformis.
ACTINODAPHNE (Lauraceae) sp.: Xenostele echinacea.
ADENOPHORA (Campanulaceae) divaricata Franch. & Sav., A. pereskiaefolia G. Don, A. polymorpha Ledeb., A. remotifolia Miq., A. rupicola Hemsl., A. scabridula Nannf., A. verticillata Fisch., A. sp.: Coleosporium campanulae.
Adenophora jasionifolia Franch., Puccinia adenophorae-verticillatae.
Adenophora remotifolia Miq.: Puccinia adenophorae.
Adenophora sp.: Aecidium adenophorae.

[1]Cooperative investigations between the Purdue University Agricultural Experiment Station and the Division of Mycology and Disease Survey, Bureau of Plant Industry, Soils, and Agricultural Engineering, United States Department of Agriculture. Journal Paper Number 479, of the Purdue University Agricultural Experiment Station. Contribution from the Department of Botany and Plant Pathology.
[2]Purdue University Agricultural Experiment Station, Lafayette, Indiana.
[3]United Nations Food and Agricultural Organization, Washington, D. C.

ADIANTUM (Polypodiaceae) pedatum L.: Uredinopsis adianti.
ADOXA (Adoxaceae) moscatellina L.: Puccinia argentata.
AECIDIUM acanthopanicis Diet.: Acanthopanax spinosa (35, 38).
Aecidium adenophorae Jacz.: Adenophora sp. (1).
Aecidium ainsliaeae Diet.: Ainsliaea acerifolia (1).
Aecidium akebiae P. Henn.: Akebia quinata (1, 23, 35, 38, 44); A. trifoliata (1, 35, 38).
Aecidium alaterni Maire: Rhamnus sp. (1).
Aecidium anningense Tai: Sophora viciifolia (31).
Aecidium asterum Schw., see Puccinia extensicola.
Aecidium atractylidis Diet., see Puccinia aomoriensis.
Aecidium bupleuri-sacchalinensis Miyake, see Puccinia miyoshiana.
Aecidium callistephi Miyake: Callistephium sp. (1).
Aecidium calystegiae Desm., see Puccinia convolvuli.
Aecidium campylotropi Tai: Campylotropis polyantha (31).
Aecidium cardui Syd.: Carduus crispus (31); C. acanthoides (44).
Aecidium caulophylli Kom.: Leontice robustum (1).
Aecidium cimicifugatum Schw., see Puccinia rubigo-vera.
Aecidium circaeae Ces. & Mont., see Puccinia circaeae-caricis.
Aecidium clerodendri P. Henn.: Clerodendron paniculatum (16).
Aecidium compositarum Mart.: Cacalia hastata (1).
Aecidium deutziae Diet., see Puccinia kusanoi.
Aecidium dispori Diet.: Disporum pullum (22); D. sp. (1, 31, 35, 38); Polygonatum sp. (1).
Aecidium dracunculi Thuem., see Puccinia atrofusca.
Aecidium elaeagni Diet.: Elaeagnus angustifolia (31); E. multiflora (1, 44); E. pungens (1, 22, 24, 25, 31, 35, 38, 44); E. sp. (1, 31, 35, 38).
Aecidium elaeagni-umbellatae Diet.: Elaeagnus multiflora (35, 38).
Aecidium enkianthi Diet.: Enkianthus chinensis (22).
Aecidium eritrichii P. Henn.: Trigonotis peduncularis (14).
Aecidium euphorbiae Gmel.: Euphorbia lunulata (25); E. pekinensis (1, 23, 28).
Aecidium foetidum Diet.: Mazus rugosus (1, 44); M. stachydifolius (22, 31); M. sp. (5).
Aecidium formosanum Syd.: Emilia sonchifolia (13, 16).
Aecidium fraxini-bungeanae Diet.: Chionanthus retusus (35, 38); Fraxinus chinensis (1, 22, 28, 31, 44); F. rhynchophyllus (1, 23, 31, 35, 38); F. sp. (1, 5, 44).
Aecidium galii A. & S.: Galium aparine (1, 22, 44). This is probably Puccinia punctata.
Aecidium girardiniae Syd.: Girardinia sp. (5). This may be the aecial stage of Puccinia caricis.
Aecidium hamamelidis Diet.: Corylopsis platypetala (23); C. veitchiana (24).
Aecidium hydrangeae Pat.: Hydrangea serrata (23); H. strigosa (35, 38); H. sp. (1).
Aecidium hydrangiicola P. Henn.: Hydrangea umbellata (1, 38).
Aecidium isopyri Schroet.: Semiaquilegia adoxoides (1, 44).
Aecidium justiciae P. Henn.: Justicia sp. (1, 35, 38).
Aecidium kaernbachii P. Henn.: Ipomoea sp. (25, 35, 38).
Aecidium klugkistianum Diet.: Ligustrum ibota (5); L. lucidum (1, 35, 38, 44); L. quihoni (1, 35, 38, 44); L. sinensis (44); L. sp. (1, 31).
Aecidium koreaense P. Henn., see Puccinia australis.
Aecidium ligustricola Cumm.: Ligustrum sp. (5).
Aecidium ligulariae Thuem., see Puccinia eriophori.
Aecidium machili P. Henn.: Machilus bournei (22, 31).
Aecidium meliosmae Keissler: Meliosma kirkii (1); M. stewardii (44).
Aecidium meliosmae-myrianthae P. Henn. & Shirai: Meliosma myriantha (1, 35, 38); M. parviflora (35, 38); M. oldhami (1, 44); M. stewardii (1).
Aecidium meliosmae-pungentis P. Henn.: Meliosma cuneifolia (44).
Aecidium mori Barcl.: Broussonetia kazinoki (1); Morus alba (1, 22, 23, 31, 35, 38, 44); M. australis (31).
Aecidium orbiculare Barcl.: Clematis sp. (31).
Aecidium osmanthi Syd. & Butl.: Osmanthus fragrans (31, 44).
Aecidium oxytropidis Thuem., see Uromyces lapponicus.
Aecidium paederiae Diet., see Puccinia zoysiae.
Aecidium paeoniae Kom.: Paeonia albiflora (1, 14).
Aecidium patriniae P. Henn., see Puccinia hemerocallidis.
Aecidium phyllanthi P. Henn.: Phyllanthus flexuosus (1, 35, 38).
Aecidium plectranthi Barcl.: Plectranthus glaucocalyx (1).

Aecidium polygoni-cuspidatae Diet.: Polygonum cuspidatum (1); P. sp. (5).
Aecidium pourthiae Syd., see Gymnosporangium japonicum.
Aecidium pulcherrimum Rav., see Puccinia coronata.
Aecidium quinatum Syd.: Elaeagnus lanceolatus (5).
Aecidium ranunculacearum DC.: Anemone vitifolia (22); A. sp. (1); Ranunculus cantoniensis (22); R. japonicus (28).
Aecidium raphiolepidis Syd.: Raphiolepis indica (1).
Aecidium rhamni Gmel., see Puccinia coronata.
Aecidium rhamni-japonici Diet.: Rhamnus sp. (31).
Aecidium rubiae Diet.: Rubia cordifolia (14, 25).
Aecidium sageretiae P. Henn.: Sageretia pycnophylla (44); S. sp. (1, 35, 38).
Aecidium sambuci Schw., see Puccinia bolleyana.
Aecidium scutellariae-indicae Diet.: Scutellaria sp. (35, 38).
Aecidium sedi Jacz., see Puccinia australis.
Aecidium semiaquilegiae Diet.: Semiaquilegia adoxoides (35, 38).
Aecidium shansiense Petrak: Sedum aizoon (28).
Aecidium shiraianum Syd.: Cimicifuga simplex (1).
Aecidium sino-rhododendri M. Wilson: Rhododendron calvescentum (45).
Aecidium smilacis Schw.: Smilax china (31, 42); S. sp. (31, 35, 38). A. smilacis is the aecial stage of Puccinia arundinariae Schw., which is not known to occur in the Orient. No Aecidium seen by us on Asiatic species of Smilax can be referred to A. smilacis.
Aecidium sommerfeltii Johans., see Puccinia septentrionalis.
Aecidium staphyleae Miura: Staphylea bumalda (1).
Aecidium urceolatum Cooke: Thalictrum przewalskii (28).
Aecidium xanthoxyli Peck: Xanthoxylum simulans (1). This is the aecial stage of Puccinia andropogonis Schw., a rust not known to occur outside of North America. The identification is doubtless erroneous in the above report.
Aecidium xanthoxyli-schinifolii Diet.: Xanthoxylum alatum (35, 38); X. simulans (1).
Aecidium sp.: Aralia chinensis (22); Benzoin sp. (5). Eupatorium sp. (5); Litsea populifolia (22); Sambucus sieboldiana (22); Schizandra sphenanthera (22).
AEGOPODIUM (Umbelliferae) alpestre Ledeb.; Puccinia leioderma.
AELUROPUS (Gramineae) littoralis Parl.: Puccinia tankuensis; Puccinia zoysiae.
AGRIMONIA (Rosaceae) eupatoria L., A. pilosa Ledeb., A. zeylanica, A. sp.: Pucciniastrum agrimoniae.
AGROPYRON (Gramineae) ciliare (Trin.) Franch.: Puccinia agropyri-ciliaris; Puccinia coronata; Puccinia glumarum; Puccinia graminis; Puccinia rangiferina; Puccinia rubigo-vera.
Agropyron repens Beauv.: Puccinia rangiferina.
Agropyron semicostatum Vill.: Puccinia glumarum; Puccinia rubigo-vera.
Agropyron sp.: Puccinia glumarum.
AGROSTIS (Gramineae) sp.: Puccinia agrostidicola; Puccinia coronata.
AINSLIAEA (Compositae) acerifolia Schult.: Aecidium ainsliaeae.
Ainsliaea hui Diels: Puccinia ainsliaeae.
AKEBIA (Berberidaceae) quinata (Houtt.) Dcne., A. trifoliata (Thunb.) Koidz.: Aecidium akebiae.
ALBIZZIA (Leguminosae) julibrissin Durazz, A. kalkora Prain, A. sp.: Ravenelia japonica.
Albizzia lebbek Benth.: Sphaerophragmium acaciae.
Albizzia sp.: Ravenelia sessilis.
ALEURITIS (Euphorbiaceae) sp.: Melampsora aleuritidis.
ALLIUM (Liliaceae) bakeri Regel, A. fistulosum L., A. longistilum Baker, A. odorum L., A. scorodoprasum L., A. sp.: Puccinia allii.
Allium fistulosum L., A. tenuissimum L., A. sp.: Puccinia porri.
Allium victorialis L.: Uromyces allii-victorialis.
ALNUS (Betulaceae) cremastogene Burk.: Melampsoridium alni.
Alnus hirsuta (Spach) Rupr.: Melampsoridium hiratsukanum.
ALOPECURUS (Gramineae) aequalis Sabol, A. amurensis Kom., A. geniculatus L., A. japonicus Steud., A. pratensis L., A. sp.: Uromyces alopecuri.
AMELANCHIER (Rosaceae) sp.: Coleopuccinia sinensis.
AMPELOPSIS (Vitaceae) brevipedunculata (Maxim.) Tautv., A. japonica (Thunb.) Mak.: Phakopsora ampelopsidis.
Ampelopsis sp.: Pucciniostele hashiokai.
ANAPHALIS (Compositae) sp.: Miyagia anaphalidis.

ANDROPOGON (Gramineae), see also Cymbopogon.
Andropogon annulatus Forsk.: Puccinia cesatii.
Andropogon ischaemum L.: Puccinia cesatii; Uromyces clignyi.
Andropogon micranthus Kunth: Puccinia erythraeensis.
Andropogon sp.: Phakopsora incompleta, Puccinia duthiae.
ANEILEMA (Commelinaceae) sp.: Uromyces commelinae.
ANEMONE (Ranunculaceae) chinensis Bunge, see Pulsatilla chinensis.
Anemone dahurica Fisch., see Pulsatilla dahurica.
Anemone vitifolia Buch.-Ham.: Aecidium ranunculacearum.
Anemone sp.: Aecidium ranunculacearum; Coleosporium pulsatillae; Puccinia rubigo-vera.
ANGELICA (Umbelliferae) dahurica Buch.-Ham.; A. decursiva Franch. & Sav.: Puccinia nanbuana.
Angelica miqueliana Max.: Puccinia angelicicola.
Angelica sinuata H. Wolff; Angelica tshiliensis H. Wolff; Angelica sp.: Puccinia nanbuana.
ANTHOGONIUM (Orchidaceae) gracile Wall.: Coleosporium bletiae.
ANTIDESMA (Euphorbiaceae) gracile Hemsl.: Crossopsora antidesmae-dioicae.
APLUDA (Gramineae) mutica L.: Uromyces inayati.
APOCYNUM (Apocynaceae) venetum L.: Melampsora apocyni.
ARACHIS (Leguminosae) hypogoea L.: Puccinia arachidis.
ARALIA (Araliaceae) chinensis L.: Aecidium sp.
Aralia elata (Miq.) Seem.: Nyssopsora thwaitesii.
Aralia mandshurica Maxim., see Aralia elata.
ARCTIUM (Compositae) majus Bernh.: Puccinia bardanae.
ARISTOLOCHIA (Aristolochiaceae) sp.: Puccinia aristolochiae.
ARTEMISIA (Compositae) annua L.: Puccinia absinthii.
Artemisia capellaris Thunb.: Puccinia absinthii.
Artemisia desertorum Spreng.: Puccinia absinthii.
Artemisia dracunculus L.: Phakopsora artemisiae.
Artemisia dubia Wall.: Puccinia absinthii.
Artemisia eriopoda Bunge: Puccinia phragmidioides.
Artemisia frigida Willd.: Puccinia artemisiae-keiskianae.
Artemisia japonica Thunb.: Puccinia absinthii; Puccinia ferruginosa; Puccinia millefolii.
Artemisia keiskiana Miq.: Puccinia artemisiae-keiskianae.
Artemisia laciniata Willd.: Puccinia atrofusca.
Artemisia mongolica Fisch.: Puccinia absinthii.
Artemisia sacrorum Ledeb.: Phakopsora compositarum; Puccinia absinthii.
Artemisia sieversiana Willd.: Puccinia absinthii.
Artemisia vulgaris L.: Phakopsora compositarum; Puccinia absinthii; Puccinia artemisiella; Puccinia atrofusca; Puccinia ferruginosa; Puccinia millefolii; Puccinia tanaceti.
Artemisia sp.: Phakopsora artemisiae; Phakopsora compositarum; Puccinia absinthii; Puccinia adjuncta; Puccinia ferruginosa; Puccinia millefolii; Puccinia tanaceti; Uromyces oblongisporus (1).
ARTHRAXON (Gramineae) hispidus (Thunb.) Makino: Puccinia arthraxonis; Uredo arthraxonis-ciliaris.
Arthraxon lanceolatum Hochst.: Puccinia aestivalis.
Arthraxon sp.: Puccinia arthraxonis; Uredo arthraxonis-ciliaris.
ARUNDINELLA (Gramineae) anomala Steud.: Puccinia arundinellae; Puccinia arundinellae-anomalae.
Arundinella arundinacea DC.: Puccinia coronata.
Arundinella nepalensis Trin.: Puccinia arundinellae.
Arundinella setosa Trin.: Puccinia arundinellae; Puccinia arundinellae-setosae.
Arundinella sp.: Puccinia arundinellae; Puccinia coronata.
ARUNDINARIA (Gramineae) sp.: Puccinia kusanoi; Puccinia phyllostachydis; Stereostratum corticioides.
ARUNDO (Gramineae) donax L.: Uredo arundinis-donacis.
ASARUM (Aristolochiaceae) sp.: Puccinia asaricola.
ASPARAGUS (Liliaceae) sp.: Puccinia asparagi-lucidi.
ASTER (Compositae) ageratoides Turcz.: Coleosporium asterum.
Aster altaicus Willd.: Coleosporium asterum.
Aster harrowianus Diels: Puccinia extensicola.
Aster hispidus Thunb.: Phakopsora compositarum.

Aster holophyllus Hemsl.: Coleosporium asterum.
Aster indicus L., see Asteromoea indica.
Aster scaber Thunb.: Coleosporium asterum; Puccinia extensicola.
Aster tataricus L.: Coleosporium asterum.
Aster trinervis Roxb.: Coleosporium asterum; Puccinia extensicola.
Aster sp.: Coleosporium asterum; Phakopsora artemisiae.
ASTEROMOEA (Compositae) indica L., A. integrifolia (Turcz.) Loess., A. mongolica (Franch.) Kitam.: Coleosporium asterum.
ASTILBE (Saxifragaceae) chinensis Franch. & Sav.: Pucciniostele mandshurica.
Astilbe thunbergii Miq.: Pucciniostele clarkiana.
ASTRAGALUS (Leguminosae) scaberrimus Bunge, A. sinicus L., A. sp.: Uromyces punctatus.
ASYNEUMA (Campanulaceae) fulgens (Wall.) Briq.: Coleosporium campanulae.
ATRACTYLIS (Compositae), see Atractylodes.
ATRACTYLODES (Compositae) chinensis (Bunge) Koidz.: Puccinia aomoriensis.
Atractylodes ovata Thunb.: Puccinia aomoriensis; Puccinia hieracii.
AVENA (Gramineae) sativa L.; Puccinia coronata; Puccinia graminis.
AZUKIA (Leguminosae) subtrilobata (T. & S.) Tak., A. typica (Pain.) Miura; Uromyces phaseoli.
BAMBUSA (Gramineae) spinosa Roxb.: Puccinia longicornis; Uredo ignava.
Bambusa tesselata Munro: Puccinia mitriformis.
Bambusa sp.: Kweilingia bambusae; Puccinia kwanhsiensis; Puccinia longicornis.
Bambusae undet.: Puccinia phyllostachydis.
BECKMANIA (Gramineae) syzygachne Fernald: Puccinia coronata.
BELAMCANDA (Iridaceae) chinensis DC.: Puccinia belamcandae.
BENZOIN (Lauraceae) sp.: Aecidium sp.; Puccinia aequitatis; Puccinia cara; Puccinia lauricola; Puccinia seposita.
BERBERIS (Berberidaceae) acuminata Franch.: Puccinia graminis.
Berberis amurensis Rupr.: Puccinia graminis; Puccinia pygmaea.
Berberis dielsiana Fedde, B. gagnepainii Schneid., B. gilgiana Fedde, B. henayana Schneid., B. julianae Schneid., B. levis Franch., B. poiretii Schneid; B. pruinosa Franch., B. sargentiana Schneid., B. silva-taroucana Schneid., B. virgetorum Schneid., B. wilsonae Hemsl.: Puccinia graminis.
BERCHEMIA (Rhamnaceae) racemosa S. & Z., B. sp.: Puccinia coronata.
BIDENS (Compositae) pilosa L.: Uromyces bidenticola.
BLETIA (Orchidaceae) hyacinthina R.Br.: Coleosporium bletiae.
BOEHMERIA (Urticaceae) sp.: Puccinia fusispora.
BOTHRIOCHLOA (Gramineae) pertusa (L.) A. Camus: Puccinia duthiae.
BRACHYBOTRYS (Boraginaceae) paridifolius Max.: Puccinia brachybotrydis; Thekopsora brachybotrydis.
BRACHYPODIUM (Gramineae) sylvaticum (Huds.) Roem. & Sch.: Puccinia baryi; Puccinia coronata.
Brachypodium sp.: Puccinia brachysora; Puccinia coronata.
BRASSAIOPSIS (Araliaceae) palmata Kurz; Nyssopsora thwaitesii.
BRIDELIA (Euphorbiaceae) monoica Merr.: Phakopsora cingens.
BROMUS (Gramineae) aspera Murray, see B. ciliatus.
Bromus ciliatus L.: Puccinia coronata.
Bromus sp: Puccinia rubigo-vera.
BROUSSONETIA (Moraceae) kazinoki Sieb.: Aecidium mori.
Broussonetia papyrifera L'Her.: Cerotelium fici.
BUBAKIA, see Phakopsora.
BULBOSTYLIS (Cyperaceae) sp.: Puccinia liberta.
BUPLEURUM (Umbelliferae) falcatum L.: Puccinia bupleuri; Puccinia miyoshiana.
Bupleurum longeradiatum Turcz.: Puccinia bupleuri.
CACALIA (Compositae) auriculata DC.: Coleosporium cacaliae.
Cacalia hastata L.: Aecidium compositarum; Coleosporium cacaliae; Puccinia tranzschelii.
CAEOMA cheoanum Cumm.: Rubus sp. (5).
Caeoma clematidis Thuem., see Coleosporium clematidis.
Caeoma fumariae Link, see Melampsora magnusiana.
Caeoma makinoi Kusano: Prunus cerasus (1); P. mandshurica (1, 17); P. sp. (19).
Caeoma warburgianum P. Henn.: Rosa banksiae (31); R. longicuspis (31); R. sp. (1).
CAJANUS (Leguminosae) cajan (L.) Millsp.: Uromyces dolicholi.

CALAMAGROSTIS (Gramineae) arundinacea L.: Puccinia coronata; Puccinia pygmaea; Puccinia rangiferina.
Calamagrostis epigejos Roth: Puccinia epigejos; Puccinia coronata; Puccinia pygmaea.
Calamagrostis langsdorfii Trin.: Puccinia rangiferina.
Calamagrostis sp.: Puccinia coronata; Puccinia hierochloae; Puccinia rangiferina.
CALAMINTHA (Labiatae) chinensis Benth.: Puccinia menthae.
CALLICARPA (Verbenaceae) cana L.: Uredo callicarpi.
Callicarpa sp.: Kuehneola callicarpi; Uromyces callicarpae.
CALLISTEPHIUM (Compositae) sp.: Aecidium callistephi.
CALLISTEPHUS (Compositae) chinensis Nees: Coleosporium asterum.
Caltha (Ranunculaceae) membranacea N. Schipcz.: Puccinia calthaecola.
Caltha palustris L.: Puccinia calthae.
CALYSTEGIA (Convolvulaceae) hederacea Wall., C. japonica Choisy, C. soldanella R.Br., C. subvolubilis G. Don: Puccinia convolvuli.
CAMPANUMAEA (Campanulaceae) sp.: Puccinia campanumaeae.
CAMPTANDRA (Zingiberaceae) yunnanensis (Gagnep.) K. Schum.: Puccinia roscoeae.
CAMPYLOTROPIS (Leguminosae) balfouriana Schindl.: Uromyces rugulosus.
Campylotropis chinensis (Bunge) Schindl.: Uromyces lespedezae-macrocarpae.
Campylotropis hirtella (Franch.) Schindl.: Uromyces rugulosus.
Campylotropis macrocarpa (Bunge) Rehd.: Uromyces lespedezae-procumbentis.
Campylotropis polyantha (Franch.) Schindl.: Aecidium campylotropi; Uromyces rugulosus.
CAPILLIPEDIUM (Gramineae) parviflorum Stapf.: Puccinia erythraeensis.
CARAGANA (Leguminosae) ambigua Stocks, C. chamlagu Lam., C. frutex (L.) K.Kock (C. frutescens DC.), C. microphylla Lam., C. rossa Lam., C. sophoraefolia Tausch.: Uromyces genistae-tinctoriae.
CARDUUS (Compositae) acanthoides L.: Puccinia carduorum.
Carduus crispus L.: Aecidium cardui; Puccinia carduorum.
CAREX (Cyperaceae) baccans Nees: Puccinia constata.
Carex brunnea Thunb.: Puccinia caricis; Puccinia caricis-brunneae.
Carex caespitosa L.: Puccinia silvatica.
Carex cruciata Wahl.: Puccinia caricis.
Carex filicina Nees: Puccinia caricis; Puccinia caricis-filicinae.
Carex fluviatilis Boott: Puccinia sp.
Carex heterolepis Bunge: Puccinia yokukurae.
Carex lanceolata Boott: Puccinia aomoriensis; Puccinia caricis.
Carex neurocarpi Maxim.: Puccinia silvatica.
Carex nubigena D. Don: Puccinia caricis-montanae.
Carex pisiformis Boott: Puccinia aomoriensis.
Carex siderosticta Hance: Puccinia caricis-siderostictae; Puccinia mandshurica; Puccinia miyakii.
Carex stenophylla Wahl.: Puccinia atrofusca.
Carex vesicaria L.: Puccinia caricis.
Carex sp.: Puccinia caricis; Puccinia caricis-gibbae; Puccinia dioicae; Puccinia hyalina; Puccinia silvatica; Puccinia subhyalina; Uromyces perigynius.
CARPESIUM (Compositae) abrotanoides L., C. cernuum L., C. sp.: Coleosporium carpesii.
CARPINUS (Betulaceae) sp.: Melampsoridium carpini.
CARTHAMUS (Compositae) tinctorius L.: Puccinia carthami.
CASTANEA (Fagaceae) henryi Rehd. & Wils.: Cronartium quercuum.
Castanea mollissima Blume: Cronartium quercuum; Pucciniastrum castaneae.
Castanea sp.: Pucciniastrum castaneae.
CAULOPHYLLUM (Berberidaceae), see Leontice.
CEDRELA (Meliaceae) sinensis Juss.: Nyssopsora cedrelae; Phakopsora cheoana.
CEPHALONOPLOS (Compositae) segetum Kitam., C. setosum Kitam.: Puccinia obtegens.
CERASTIUM (Caryophyllaceae) sp.: Melampsorella caryophyllacearum.
CEROTELIUM desmium Arth. see Phakopsora desmium.
Cerotelium fici (Cast.) Arth.: Broussonetia papyrifera (1, 44); Ficus carica (1, 44); Morus sp. (31).
CHAENOMELES (Rosaceae) japonica (Thunb.) Lindl., C. lagenaria (Loisel.) Koidz., C. sinensis (Thouin) Koehne, C. sp.: Gymnosporangium haraeanum.
CHAMAENERION (Onagraceae) angustifolium Scop.: Pucciniastrum epilobii.
CHIONANTHES (Oleaceae) retusus Lindl. & Paxton: Aecidium fraxini-bungeanae.
CHNOOPSORA itoana Hirats. f., see Melampsorella itoana.

CHRYSANTHEMUM (Compositae) indicum L.: Phakopsora artemisiae; Phakopsora compositarum; Puccinia chrysanthemi; Puccinia horiana.
Chrysanthemum sibiricum Fisch.: Phakopsora compositarum; Puccinia chrysanthemi.
Chrysanthemum zawadskii Herbich: Puccinia chrysanthemi.
Chrysanthemum sp.: Phakopsora artemisiae; Puccinia chrysanthemi.
CHRYSOMYXA bambusae Teng, see Kweilingia bambusae.
Chrysomyxa dietelii Syd.: Rhododendron trichocladum (31).
Chrysomyxa expansa Diet.: Rhododendron sp. (36).
Chrysomyxa ledi de Bary: Picea likiangensis (19).
Chrysomyxa pyrolae Rostr.: Pyrola rotundifolia (1).
Chrysomyxa rhododendri de Bary: Rhododendron dauricum (1, 14); R. decorum (31); R. faberi (22); R. micranthum (25).
Chrysomyxa tsugae Teng, see Chrysomyxa tsugae-yunnanensis.
Chrysomyxa tsugae-yunnanensis Teng: Tsuga yunnanensis (36, 37).
CHRYSOSPLENIUM (Saxifragaceae) alternifolium L., C. griffithii: Puccinia chrysosplenii.
CICUTA (Umbelliferae) virosa L.: Puccinia cicutae.
CIMICIFUGA (Ranunculaceae) dahurica Maxim: Coleosporium cimicifugatum.
Cimicifuga foetida L.: Coleosporium cimicifugatum.
Cimicifuga simplex Wormsk.: Aecidium shiraianum; Coleosporium cimicifugatum.
Cimicifuga sp.: Puccinia rubigo-vera.
CINNAMOMUM (Lauraceae) sp.: Puccinia cinnamomi; Puccinia cinnamomicola.
CIRCAEA (Onagraceae) caulescens Nakai: Pucciniastrum circaeae.
Circaea cordata Royle: Puccinia circaeae.
Circaea imaicola (Aschers. & Magn.) Hand.-Mazz.: Puccinia circaeae; Puccinia circaeae-caricis.
CIRSIUM (Compositae) arvensis (L.) Scop.: Puccinia cirsii; Puccinia obtegens.
Cirsium chinense Champ.: Puccinia cirsii-maritimi.
Cirsium segetum Bunge: Puccinia cirsii; Puccinia obtegens.
Cirsium sp.: Puccinia cirsii; Puccinia cirsii-maritimi; Puccinia dioicae; Puccinia obtegens.
CLEISTOGENES (Gramineae), see Diplachne.
CLEMATIS (Ranunculaceae) angustifolia Jacq.: Coleosporium clematidis.
Clematis apiifolia DC.: Coleosporium clematidis; Coleosporium clematidis-apiifoliae.
Clematis armandi Franch.: Coleosporium clematidis.
Clematis aquilegifolium L.: Puccinia rubigo-vera.
Clematis benthamiana Hemsl.: C. brevicaudata: Coleosporium campanulae.
Clematis chinensis Osbeck: Coleosporium clematidis; Puccinia rubigo-vera.
Clematis chrysocoma Franch.: Coleosporium clematidis.
Clematis connata DC.: Puccinia clematidicola.
Clematis fusca Turcz., C. grata Wall.: Coleosporium clematidis.
Clematis heracleifolia DC.: Coleosporium clematidis; Puccinia rubigo-vera.
Clematis hexapetala Pall., C. mandshurica Rupr.: Coleosporium clematidis.
Clematis montana Buch.-Ham.: Coleosporium clematidis; Coleosporium clematidis-apiifoliae.
Clematis orientalis L.: Coleosporium clematidis.
Clematis paniculata Thunb.: Coleosporium clematidis; Puccinia rubigo-vera.
Clematis peterae Hand.-Mazz.: Coleosporium clematidis; Puccinia wattiana.
Clematis potanini Maxim.: Puccinia rubigo-vera.
Clematis recta L.: Coleosporium clematidis.
Clematis urcinata Champ.: Puccinia rubigo-vera.
Clematis sp.: Aecidium orbiculare; Coleosporium clematidis; Coleosporium clematidis-apiifoliae; Puccinia rubigo-vera; Puccinia wattiana.
CLERODENDRON (Verbenaceae) inerme Gaertn.: Puccinia erebia.
Clerodendron paniculatum L.: Aecidium clerodendri.
Clerodendron trichotomum Thunb., C. sp.: Coleosporium clerodendri.
CLINELYMUS, see Elymus.
CODONOPSIS (Campanulaceae) lanceolata Benth. & Hook.: Coleosporium horianum.
COFFEA (Rubiaceae) arabica: Hemileia vastatrix.
COLEBROOKIA (Labiatae) oppositifolia Sm.: Uredo colebrookiae.
COLEOPUCCINIA kunmingensis Tai: Cotoneaster franchetii (32); C. microphylla (32).
Coleopuccinia simplex Diet.: Eriobotrya japonica (36); E. sp. (8, 33, 44).
Coleopuccinia sinensis Pat.: Amelanchier sp. (1); Cotoneaster racemiflora (28); C. tenuipes (28); C. sp. (1, 37).

COLEOSPORIUM aconiti Thuem.: Aconitum vilmorinianum (31).
Coleosporium arundinae Syd.: Spathoglottis pubescens (31).
Coleosporium asterum (Diet.) Syd.: Aster ageratoides (14); A. altaicus (44); A. holophyllus (1, 23, 25, 44); A. scaber (1, 14, 44); A. tataricus (1); A. trinervis (1, 23, 24, 44); A. sp. (1, 4, 16, 31, 35, 38, 44); Asteromoea indica (22, 25); A. integrifolia (1); A. mongolica (1); Callistephus chinensis (31); Pinus massoniana (1, 35, 38). Records originally published as Coleosporium solidaginis have been incorporated here since it is doubtful that the species occurs in China.
Coleosporium bletiae Diet.: Anthogonium gracile (28); Bletia hyacinthina (1, 4, 44); undet. Orchidaceae (31).
Coleosporium cacaliae Otth: Cacalia auriculata (14); C. hastata (14).
Coleosporium campanulae Lév.: Adenophora divaricata (14); A. pereskiaefolia (14); A. polymorpha (1); A. remotifolia (44); A. rupincola (23); A. scabridula (23); A. verticillata (19); A. sp. (1, 4); Asyneuma fulgens (31); Lobelia pyramidalis (4); Platycodon sp. (4); Wahlenbergia marginata (31).
Coleosporium carpesii Sacc.: Carpesium abrotanoides (1, 31); C. cernuum (22, 31); C. sp. (4, 22, 31).
Coleosporium cheoanum Cumm.: Coleus sp. (4).
Coleosporium cimicifugatum Thuem.: Cimicifuga dahurica (15); C. foetida (1, 31); C. simplex (1, 14).
Coleosporium clematidis Barcl.: Clematis angustifolia (25); C. apiifolia (25); C. armandi (19); C. benthamiana (25); C. brevicaudata (25, 31); C. chinensis (24, 25); C. chrysocoma (31); C. fusca (1); C. grata (1, 4, 35, 38); C. heracleifolia (1); C. hexapetala (15); C. mandshurica (1, 14); C. montana (4, 22, 31); C. orientalis (1); C. paniculata (1, 35, 38); C. peterae (31); C. recta (18); C. sp. (1, 4, 16, 31).
Coleosporium clematidis-apiifoliae Diet.: Clematis apiifolia (1); C. montana (24).
Coleosporium clerodendri Diet.: Clerodendron trichotomum (1, 44); C. sp. (35, 38).
Coleosporium elephantopodis Thuem.: Elephantopus sp. (4).
Coleosporium eupatorii Arth.: Eupatorium lindleyanum (4, 31); E. sp. (4, 35, 38).
Coleosporium euphrasiae (Schum.) Wint.: Pedicularis cyathophylla (28).
Coleosporium evodiae Diet.: Evodia meliaefolia (4, 16); E. officinalis (4, 22, 31); E. rutaecarpa (31); E. sp. (4, 31, 35, 38).
Coleosporium fauriae Syd.: undet. Saxifragaceae (31).
Coleosporium geranii Pat.: Geranium strigosum (31); G. sp. (1).
Coleosporium horianum P. Henn.: Codonopsis lanceolata (1, 14, 35, 38, 44).
Coleosporium inulae (Kunze) Ed. Fisch.: Inula serrata (31).
Coleosporium leptodermidis (Barcl.) Syd.: Leptodermis glomerata (31); L. pilosa (31); L. potanini (31).
Coleosporium ligulariae Thuem.: Ligularia dictyoneura (31); L. lapathifolius (31); L. sp. (35, 38).
Coleosporium melampyri Tul.: Melampyrum roseum (1, 14, 35, 38).
Coleosporium paederiae Diet.: Paederia foetida (31); P. sp. (16, 31).
Coleosporium pedicularidis Tai: Pedicularis deltoides (31); P. gracilis (31); P. racemosa (31).
Coleosporium perillae Syd.: Elsholtzia cristata (44); E. patrinii (31); E. ochroleuca (31); E. rugulosa (31); Mosla lanceolata (22); M. punctata (1, 35, 38); M. sinensis (4); M. sp. (16); Perilla frutescens (14, 17, 22, 31, 44); P. nankinensis (1, 22, 31, 35, 38); P. ocymoides (1, 4); P. puteaceus (1, 18, 20).
Coleosporium phellodendri Kom.: Phellodendron amurensis (1, 14, 18, 20); P. sachalinensis (1).
Coleosporium plectranthi Barcl.: Plectranthus bulleyanus (31); P. coetsa (31); P. eriocalyx (31); P. glaucocalyx (1, 44); P. inflexus (1, 14); P. nervosus (22, 31); P. phyllopodus (31); P. racemosus (4); P. sculponeatus (31); P. striatus (31).
Coleosporium pulsatillae Lév.: Pulsatilla chinensis (1, 14, 23, 25, 35, 38, 44); P. dahurica (14).
Coleosporium rubiicola Cumm.: Rubia cordifolia (4).
Coleosporium saussureae Thuem.: Saussurea cordifolia (24); S. glomerata (25); S. japonica (1); S. manshurica (14); S. maximowiczii (1, 44); S. odontolepis (14); S. peduncularis (31); S. pulchella (14); S. serrata (24); S. triangulata (24); S. ussuriensis (25); S. sp. (4).
Coleosporium senecionis Fries: Senecio argunensis (1, 18); S. canabifolius (14); S. densiflorus (22, 31); S. dianthus (31).
Coleosporium solidaginis, see Coleosporium asterum.
Coleosporium sonchi-arvensis Lev.: undet. Compositae (1).

Coleosporium violae Cumm.: Viola limprechtiana (4).
Coleosporium xanthoxyli Diet. & Syd.: Xanthoxylum acanthopodium (31); X. alatum (1, 31, 44); X. simulans (8, 23, 30, 44); X. sp. (4, 8, 35, 38).
Coleosporium sp.: Gardenia angusta (22); Siegesbeckia orientalis (4).
COLEUS (Labiatae) sp.: Coleosporium cheoanum.
COLQUHOUNIA (Labiatae) coccinea Wall: Puccinia leucophaea.
COMMELINA (Commelinaceae) communis L.: Uromyces commelinae.
Commelina nudiflora R. Br.: Phakopsora tecta; Uromyces commelinae.
Commelina sp.: Uromyces commelinae.
COMPOSITAE undet.: Coleosporium sonchi.
CONIOGRAMME (Pteridophyta) fraxinea (Don) Diels: Hyalopsora sp.
CORIARIA (Coriariaceae) sinica Maxim.; C. sp.: Pucciniastrum coriariae.
CORYDALIS (Papaveraceae) sp.: Melampsora magnusiana.
CORYLOPSIS (Hamamelidaceae) platypetala Rehd. & Wils., C. veitchiana Bean: Aecidium hamamelidis.
Corylopsis sp.: Puccinia corylopsidis.
CORYLUS (Betulaceae) heterophylla Fish.: Pucciniastrum coryli.
COTINUS (Anacardiaceae) coggyria Scop.: Pileolaria cotini-coggyriae.
COTONEASTER (Rosaceae) adpressa Bois.: Gymnosporangium sikangense.
Cotoneaster francheti Bois., C. microphylla Lindl.: Coleopuccinia kunmingensis.
Cotoneaster multiflora Bunge: Gymnosporangium nanwutaianum.
Cotoneaster racemiflora (Desf.) K. Kock, C. tenuipes Rehd. & Wils.: Coleopuccinia sinensis.
Cotoneaster sp.: Coleopuccinia sinensis; Roestelia lacerata.
CRATAEGUS (Rosaceae) cuneata Sieb. & Zucc., C. hupehensis Sarg., C. pinnatifida Bunge: Gymnosporangium haraeanum.
Crataegus scabrifolius (Franch.) Rehd.: Gymnosporangium clavariaeforme.
Crataegus sp.: Gymnosporangium clavariaeforme; Gymnosporangium haraeanum; Gymnosporangium magnum.
CREPIS (Compositae) japonica Benth.: Puccinia crepidis-japonicae.
Crepis tectorum L.: Puccinia crepidis.
CRITESION (Gramineae), see Hordeum.
CRONARTIUM antidesmae-dioicae Syd., see Crossopsora antidesmae-dioicae.
Cronartium delavayi Pat., see Cronartium gentianeum.
Cronartium flaccidum (Alb. & Schw.) Wint.: Delphinium delavayi (31); Paeonia albiflora (1, 14, 35, 38); Pinus yunnanensis (19).
Cronartium gentianeum Thuem.: Gentiana dicta (1); G. rigescens (31); G. yunnanensis (31).
Cronartium keteleeriae Tai: Keteleeria elveyniana (31).
Cronartium quercuum Miyabe: Castanea henryi (1, 44); C. mollissima (1); Pinus massoniana (1, 22, 35, 38, 44); Quercus acutissima (8, 31); Q. fabri (1, 44); Q. glandulifera (1, 22 44); Q. glauca (1, 44); Q. serrata (1); Q. variabilis (1, 44); Q. sp. (1, 4, 8, 22, 35, 38).
Cronartium ribicola Fischer: Ribes coeleste (28); R. mandschuricum (14).
CROSSOPSORA antidesmae-dioicae (Syd.) Arth. & Cumm.: Antidesma gracile (35, 38).
CROTALARIA (Leguminosae) lonchophylla Hand.-Mazz.: Uromyces decoratus.
CRYPTOTAENIA (Umbelliferae) canadensis DC., C. japonica Hassk., C. sp.: Puccinia tokyensis.
CUCUBALUS (Caryophyllaceae) baccifer L.: Puccinia behenis.
CUDRANIA (Moraceae) sp.: Uredo sinensis.
CUPRESSUS (Pinaceae) duclouxiana Hickel: Gymnosporangium cunninghamianum.
Cupressus funebris Endl.: Gymnosporangium tsingchensis.
CYANOTIS (Commelinaceae) sp.: Uredo davaoensis.
CYDONIA (Rosaceae) japonica Pers., see Chaenomeles lagenaria.
Cydonia oblonga Mill.: Gymnosporangium haraeanum.
CYMBOPOGON (Gramineae) citratus (DC.) Staf., C. nardus Rendle: Puccinia nakanishikii.
CYNANCHUM (Asclepiadaceae) sibiricum R. Br.: Melampsora cynanchi.
CYNODON (Gramineae) dactylon Pers.: Puccinia cynodontis; Uredo cynodontis-dactylis.
CYPERUS (Cyperaceae) difformis L.: Puccinia romagnoliana.
Cyperus glomeratus L.: Puccinia cyperi.
Cyperus iria L.: Puccinia angustata; Puccinia cyperi.
Cyperus rotundus L.: Puccinia romagnoliana.
Cyperus serotinus Rottb.: Puccinia juncelli.
Cyperus sp.: Puccinia canaliculata; Puccinia cyperi; Puccinia cyperi-tagetiformis; Puccinia philippinensis.

DACTYLIS (Gramineae) glomerata L.: Puccinia rubigo-vera.
DAEDALACANTHUS (Acanthaceae) see Eranthemum.
DALBERGIA (Leguminosae) sp.: Maravalia achroa.
DAPHNE (Thymelaeaceae) odora Thunb.: Uredo daphnicola.
DELPHINIUM (Ranunculaceae) delavayi Franch.: Cronartium flaccidum.
Delphinium sp.: Puccinia rubigo-vera.
DENDROCALAMUS (Gramineae) latiflorus Munro: Uredo dendrocalami.
Dendrocalamus sp.: Uredo ignava.
DESMODIUM (Leguminosae) racemosum (Thunb.) DC.: Phakopsora meibomiae.
Desmodium yunnanense Franch.: Uromyces capitatus.
DEUTZIA (Saxifragaceae) discolor Hemsl.: Uredo deutziae.
Deutzia sp.: Puccinia kusanoi.
DEYEUXIA (Gramineae) sylvatica Kunth: Puccinia coronata; Puccinia deyeuxiae; Puccinia rangiferina.
DIANELLA (Liliaceae) ensifolia DC., D. sp.: Uredo dianella.
DIANTHUS (Caryophyllaceae) caryophyllus L.: Uromyces caryophyllinus.
Dianthus chinensis L.: Puccinia arenariae; Uromyces caryophyllinus.
Dianthus longicalyx Miq.: Uromyces caryophyllinus.
DIARRHENA (Gramineae) manshurica Maxim.: Puccinia diarrhenae.
DICLIPTERA (Acanthaceae) sp.: Puccinia shiraiana.
DIGITARIA (Gramineae) sanguinalis (L.) Scop.: Puccinia levis.
Digitaria sp.: Puccinia oahuensis.
DIOSCOREA (Dioscoreaceae) acerifolia Uline, D. nipponica Mak., D. quinqueloba Thunb.: Puccinia dioscoreae.
DIPLACHNE (Gramineae) serotina Link: Puccinia australis; Puccinia diplachnicola; Puccinia moliniae.
Diplachne sp.: Puccinia diplachnis.
DISPORUM (Liliaceae) pullum Salisb.: Aecidium dispori.
Disporum sp.: Aecidium dispori; Puccinia dispori.
DRYOPTERIS (Pteridophyta) crassirhizoma Nakai: Milesia miyabei.
Dryopteris sp.: Hyalopsora polypodii; Milesia erythrosora.
DUCHESNEA (Rosaceae) indica (Andr.) Focke: Frommea duchesneae.
EHRETIA (Boraginaceae) macrophyllum Wall.: Uredo ehretiae.
Ehretia sp.: Phakopsora ehretiae.
ELAEAGNUS (Elaeagnaceae) angustifolia L.: Aecidium elaeagni.
Elaeagnus lanceolatus Warb.: Aecidium quinatum; Puccinia elaeagni.
Elaeagnus multiflora Thunb.: Aecidium elaeagni; Aecidium elaeagni-umbellatae.
Elaeagnus pungens Thunb.: Aecidium elaeagni.
Elaeagnus sp.: Aecidium elaeagni; Puccinia achroa.
ELEOCHARIS (Cyperaceae) tuberosus Schult.: Puccinia liberta.
ELEPHANTOPUS (Compositae) sp.: Coleosporium elephantopodis.
ELSHOLTZIA (Labiatae) cristata Willd., E. patrini Garcke, E. ochroleuca Dunn, E. rugulosa Hemsl.: Coleosporium perillae.
ELYMUS (Gramineae) sibiricus L.: Puccinia elymina; Puccinia rubigo-vera.
ENDOPHYLLUM griffithiae (P. Henn.) Racib.: Randia sinensis (1).
EMILIA (Compositae) sonchifolia DC.: Aecidium formosanum.
ENKIANTHUS (Ericaceae) chinensis Franch.: Aecidium enkianthi.
EPILOBIUM (Onagraceae) sp.: Puccinia epilobii-tetragoni.
EPIMEDIUM (Berberidaceae) sp.: Puccinia epimedii; Puccinia graminis.
EPIPREMNUM (Araceae) mirabile Schott.: Puccinia hashiokai.
ERAGROSTIS (Gramineae) ferruginea Beauv.: Puccinia emaculata; Puccinia eragrostidis-ferrugineae.
Eragrostis sp.: Puccinia morigera.
ERANTHEMUM (Acanthaceae) nervosum R. Br.: Puccinia polystegia.
ERIANTHUS (Gramineae) fastigiatus Nees: Puccinia eulaliae.
Erianthus fulvus Nees.: Puccinia purpurea.
ERIOBOTRYA (Rosaceae) japonica (Thunb.) Lindl., E. sp.: Coleopuccinia simplex.
ERIOCHLOA (Gramineae) villosa Kunth: Uromyces eriochloae.
EULALIA (Gramineae) quadrinervis: Puccinia polliniae-quadrinervis.
Eulalia sp.: Phakopsora incompleta.
EUPATORIUM (Compositae) lindleyanum DC.: Coleosporium eupatorii.
Eupatorium sp.: Aecidium sp.; Coleosporium eupatorii; Puccinia tenuis.

EUPHORBIA (Euphorbiaceae) chrysocoma Lév. & Van.: Melampsora euphorbiae-dulcis.
Euphorbia esula L.: Melampsora euphorbiae.
Euphorbia humifusa Willd.: Uromyces proeminens.
Euphorbia lunulata Bunge: Aecidium euphorbiae; Melampsora euphorbiae; Melampsora euphorbiae-dulcis; Melampsora euphorbiae-lunulatae.
Euphorbia pekinensis Rupr.: Aecidium euphorbiae; Melampsora euphorbiae-dulcis.
Euphorbia sieboldiana Rupr.: Melampsora euphorbiae-dulcis.
Euphorbia sp.: Melampsora euphorbiae; Melampsora euphorbiae-dulcis; Uromyces pisi; Uromyces striolatus.
EVODIA (Rutaceae) meliaefolia Benth., E. officinalis Dode, E. rutaecarpa Hook. f. & Thoms., E. sp.: Coleosporium evodiae.
FAGOPYRUM (Polygonaceae) esculentum Moench: Puccinia fagopyri.
FESTUCA (Gramineae) extremiorientalis Ohwi: Puccinia festucae.
Festuca ovina L.: Puccinia festucae-ovinae.
FICUS (Moraceae) carica L.: Cerotelium fici.
Ficus heteromorpha Hemsl., F. martini Miq.: Phakopsora hengshanensis.
Ficus sp.: Phakopsora fici-erecti.
FILIPENDULA (Rosaceae) palmata Maxim.: Triphragmium anomalum; Triphragmium ulmariae.
FIMBRISTYLIS (Cyperaceae) sp.: Puccinia fimbristylidis; Uromyces kwangsianus.
FLUEGGIA (Euphorbiaceae) sp.; Phakopsora cingens.
FRAGARIA (Rosaceae) sp.: Pucciniastrum potentillae.
FRAXINUS (Oleaceae) chinensis Roxb.: Aecidium fraxini-bungeanae; Uropyxis fraxini.
Fraxinus rhynchophyllus Hance, F. sp.: Aecidium fraxini-bungeanae.
FRITILLARIA (Liliaceae) dagana Turcz.: Puccinia hsinganensis.
Fritillaria sp.: Uromyces lilii.
FROMMEA duchesneae Arth.: Duchesnea indica (35, 38).
FUNKIA (Liliaceae), see Hosta.
GALIUM (Rubiaceae) aparine L.: Aecidium galii; Phakopsora punctiformis.
Galium asperifolium Wall.: Phakopsora punctiformis.
Galium dahuricum Turcz.: Puccinia punctata; Thekopsora guttata.
Galium verum L.: Puccinia punctata; Thekopsora guttata.
Galium sp.: Puccinia punctata.
GAMBLEOLA cornuta Massee: Mahonia sheridaniana (8).
GARDENIA (Rubiaceae) angusta Merr.: Coleosporium sp.
GENTIANA (Gentianaceae) dicta Franch.: Cronartium gentianeum.
Gentiana macrophylla Pall.: Puccinia gentianae.
Gentiana rigescens Franch.: Cronartium gentianeum.
Gentiana wutaiensis Marq.: Puccinia gentianae.
Gentiana yunnanensis Franch.: Cronartium gentianeum.
Gentiana sp.: Puccinia gentianae.
GERANIUM (Geraniaceae) dahuricum DC.: Puccinia leveillei.
Geranium eriostemon Fisch.: Puccinia leveillei; Uromyces geranii.
Geranium nepalensis Sweet, G. orientale-tibeticum Kunth, G. sibiricum, G. sp.: Uromyces geranii.
Geranium strigosum Burm.f., G. sp.: Coleosporium geranii.
GERWASIA chinensis (Diet.) Hirats. f.: Rubus amplifolius (4); R. cochinchinensis (16); R. reflexus (1); R. setchuensis (4, 31); R. hupehensis (31); R. sp. (4, 31, 35, 38).
Gerwasia rosae Tai: Rosa cymosa (31); R. roxburghii (4).
Gerwasia rubi Racib.: Rubus setchuensis (22); R. hupehensis (22). These records doubtless refer to the same rust listed above as G. chinensis. Moreover, it is probable that G. chinensis is synonymous with G. rubi, but no one has been able to obtain for examination any material of Raciborski's species.
GIRARDINIA (Urticaceae) sp.: Aecidium girardiniae.
GLECOMA (Labiatae) hederacea L., G. sp.: Puccinia glechomatis.
GLOCHIDION (Euphorbiaceae) sp.: Phakopsora formosana; Phakopsora glochidii.
GLYCERIA (Gramineae) aquatica Wahl., G. sp.: Puccinia coronata.
GLYCINE hispida Maxim., G. sojae Sieb. & Zucc., see G. max.
Glycine max Merr.: Phakopsora pachyrhizae Syd.
GLYCYRRHIZA (Leguminosae) aspera Pall.: Puccinia glycyrrhizae.
Glycyrrhiza echinata L., G. glabra L., G. glandulifera Waldst. & Kit., G. squamulosa Franch., G. uralensis Fisch.: Uromyces glycyrrhizae.

GOSSYPIUM (Malvaceae) barbadense L., G. sp.: Phakopsora desmium.
GREWIA (Tiliaceae) parviflora Bunge: Ravenelia atrides.
GUELDENSTAEDTIA (Leguminosae) delavayi Franch.: Uromyces kondoi.
Gueldenstaedtia multiflora Bunge: Uromyces genistae-tinctoriae; Uromyces kondoi.
Gueldenstaedtia stenophylla Bunge, G. sp.: Uromyces kondoi.
GYMNADENIA (Orchidaceae) canopsea R. Br.: Puccinia orchidearum-phalaridis (1).
GYMNOCONIA interstitialis Lagerh., see Gymnoconia peckiana.
Gymnoconia peckiana (Howe) Trotter: Rubus saxatilis (1).
GYMNOSPORANGIUM clavariaeforme (Jacq.) DC.: Crataegus scabrifolius (31); C. sp. (1).
Gymnosporangium cunninghamianum Barcl.: Cupressus duclouxiana (31).
Gymnosporangium fenzelianum Tai & Cheo: Malus kansuensis (33).
Gymnosporangium haraeanum Syd.: Chaenomeles japonica (23, 26); C. lagenaria (1, 22, 44); C. sinensis (31); C. sp. (35, 38); Crataegus cuneata (1, 41); C. hupehensis (1); C. pinnatifida (1, 22, 23, 33); Cydonia oblonga (44); Juniperus chinensis (1, 22, 23, 35, 36, 44); Pyrus betulifolia (1, 23, 44); P. calleryana (1, 44); P. communis (17, 35); P. lindleyi (1, 28); P. pyrifolia (1, 15, 23, 25, 28, 44); P. ussuriensis (22, 23, 25, 31, 38).
Gymnosporangium japonicum Syd.: Juniperus chinensis (1, 35, 38, 44); Photinia amphidoxa (44); P. parvifolia (1, 19, 31, 35, 38). P. villosa (1, 31, 44); Pyrus pyrifolia (19).
Gymnosporangium juniperinum (L.) Mart.: Sorbus valbrayi (31).
Gymnosporangium leve Crowell: Malus sieboldii (1).
Gymnosporangium magnum Crowell: Crataegus sp. (1).
Gymnosporangium nanwutaianum Tai & Cheo: Cotoneaster multiflora (33).
Gymnosporangium nipponicum Yamada: Sorbus alnifolia (31).
Gymnosporangium photiniae Kern, see Gymnosporangium japonicum.
Gymnosporangium sikangense Petrak: Cotoneaster adpressa (28).
Gymnosporangium tsingchensis Wei: Cupressus funebris (43).
Gymnosporangium wenshanense Tai: Photinia serrulata (31).
Gymnosporangium yamadae Miyabe: Juniperus chinensis (1, 14, 22, 23, 35, 38, 44); Malus baccata (23); M. domesticus (1); M. hupehensis (1); M. prunifolia (4); M. pumila (1, 14, 17, 35, 44); M. spectabilis (1).
GYPSOPHILA (Caryophyllaceae) oldhamiana Miq.: Puccinia gypsophilae; Uromyces caryophyllinus.
Gypsophila pacifica Kom.: Puccinia gypsophilae.
HALENIA (Gentianaceae) sibirica Borkh.: Puccinia haleniae.
HALORRHAGIS (Halorrhagidaceae) micrantha R. Br.: Puccinia halorrhagidis.
HAMASPORA acutissima Syd.: Rubus setchuensis (4); R. sp. (4, 16, 35, 38, 44).
Hamaspora benguetensis Syd.: Rubus ellipticus (31); R. sp. (4).
Hamaspora hashiokai Hirats. f.: Rubus sp. (4).
Hamaspora longissima (Thuem.) Koern.: Rubus lambertianus (1); R. sp. (8, 35, 38). These records are undoubtedly erroneous and probably should be referred to H. hashiokai, H. longissima apparently does not occur in Asia.
Hamaspora sinica Tai & Cheo: Rubus parkeri (31); R. phoenicolasius (31); R. pinnatisepalus (33); R. trianthus (22); R. sp. (4, 31, 33).
HEDYOTIS (Rubiaceae) obliquinervis Merr.: Puccinia lateritia.
HEDYSARUM (Leguminosae) obscurum L.: Uromyces hedysari-obscuri.
HELIANTHUS (Compositae) annuus L., H. tuberosus L.: Puccinia helianthi.
HEMARTHRIA (Gramineae) compressa (L.) R. Br.: Puccinia cacao.
HEMEROCALLIS (Liliaceae) citrina L., H. dumortieri Mors., H. flava L., H. fulva L., H. minor Mill., H. sp.: Puccinia hemerocallidis.
HEMIGRAPHIS (Acanthaceae) sp.: Uromyces macintirianus.
HEMILEIA vastatrix B. & Br.: Coffea arabica (16, 31, 40).
Hemileia wrightii Racib.: Wrightia pubescens (16).
HETEROPOGON (Gramineae) contortus: Puccinia filipodia.
HETEROSMILAX (Liliaceae), see Smilax.
HIERACIUM (Compositae) umbellatum L.: Puccinia hieracii.
HIEROCHLOA (Gramineae) glabra Trin.: Puccinia coronata.
Hierochloa odorata (L.) Pall.: Puccinia hierochloae.
HORDEUM (Gramineae) jubatum L.: Puccinia glumarum.
Hordeum vulgare L.: Puccinia glumarum; Puccinia hordei; Puccinia graminis.
Hordeum sp.: Puccinia hordei.
HOSTA (Liliaceae) coerulea (Andr.) Tratt.: Puccinia funkiae.

HYALOPSORA polypodii (Diet.) Magn.: Dryopteris sp. (31).
Hyalopsora sp.: Coniogramme fraxinea (7); Polypodium veitchii (7).
HYDRANGEA (Saxifragaceae) serrata (Thunb.) DC.: H. strigosa Rehd.: Aecidium hydrangeae.
Hydrangea thunbergii Sieb., see Hydrangea serrata.
Hydrangea umbellata Rehd.: Aecidium hydrangiicola.
Hydrangea sp.: Aecidium hydrangeae; Pucciniastrum hydrangeae-petiolaridis.
HYPERICUM (Hypericaceae) ascyron L.: Melampsora kusanoi.
Hypericum japonicum Thunb.: Uromyces hyperici.
Hypericum patulum Thunb.: Melampsora kusanoi.
Hypericum sampsoni Hance: Melampsora hypericorum.
Hypericum sp.: Melampsora kusanoi; Uromyces hyperici.
IDESIA (Flacourtiaceae) polycarpa Maxim.: Melampsora idesiae.
IMPATIENS (Balsaminaceae) nolitangere L.: Puccinia argentata.
Impatiens uliginosa Franch.: Puccinia impatientis-uliginosae.
Impatiens sp.: Puccinia argentata.
IMPERATA (Gramineae) cylindrica Beauv.: Puccinia rufipes.
INDIGOFERA (Leguminosae) cinerascens Franch.: Ravenelia laevis.
Indigofera dielsiana Craib, I. hancockii: Ravenelia macrocapitula.
Indigofera scabrida Dunn: Ravenelia indigoferae-scabridae.
Indigofera sp.: Ravenelia indigoferae; Uromyces sphaerocarpus; Uromyces sp.
INULA (Compositae) serrata Bur. & Franch.: Coleosporium inulae.
IPOMOEA (Convolvulaceae) sp.: Aecidium kaernbachii.
IRIS (Iridaceae) dichotoma Pall., I. ensata Thunb., I. japonica Thunb., I. setosa Pall., I. tectorum Maxim., I. sp.: Puccinia iridis.
ISOPYRUM (Ranunculaceae) adoxoides, see Semiaquilegia.
JUNCUS (Juncaceae) gracillimus Krecz. & Gontsc.: Puccinia junci.
JUNIPERUS (Pinaceae) chinensis L.: Gymnosporangium haraeanum; Gymnosporangium japonicum; Gymnosporangium yamadae.
JUSTICIA (Acanthaceae) gendarussa L.f.: Puccinia thwaitesii.
Justicia procumbens L.: Puccinia elytrariae; Puccinia shiraiana.
Justicia xerobatica W. W. Smith: Puccinia shiraiana.
Justicia sp.: Aecidium justiciae; Puccinia shiraiana.
KETELEERIA (Pinaceae) elveyniana Mast.: Cronartium keteleeriae.
KOELREUTERIA (Sapindaceae) bipinnatus Franch., K. sp.: Triphragmium koelreuteriae.
Koelreuteria paniculata Laxm.: Triphragmium chinense; Triphragmium koelreuteriae.
KUEHNEOLA callicarpae Syd.: Callicarpa sp. (4, 16).
Kuehneola fici Butl., see Cerotelium fici.
KUMMEROWIA (Leguminosae), see Lespedeza.
KWEILINGIA bambusae (Teng) Teng: Bambusa sp. (35, 38).
KYLLINGA (Cyperaceae) brevifolia Rottb.: Puccinia kyllingae-brevifoliae; Uredo kyllingae.
LACTUCA (Compositae) brevirostris Champ.: Puccinia minussensis.
Lactuca chinensis Mak.: Puccinia lactucae-repentis; Puccinia silvatica.
Lactuca debilis Benth. & Hook.: Puccinia lactucae-debilis.
Lactuca denticulata Maxim., L. indica L.: Puccinia lactucae-denticulatae; Puccinia minussensis.
Lactuca raddeana Maxim., L. sibirica B. & H.: Puccinia minussensis.
Lactuca sonchifolia Deb.: Puccinia lactucae-denticulatae.
Lactuca tatarica (DC.) C.A. Mey., L. thunbergiana Maxim.: Puccinia minussensis.
Lactuca versicolor Sch.-Bip.: Puccinia lactucae-repentis.
Lactuca sp.: Puccinia minussensis.
LASIAGROSTIS (Gramineae), see Stipa.
LAURACEAE undet.: Puccinia lauricola.
LEERSIA (Gramineae) oryzoides Swartz: Puccinia fushunensis.
Leersia sp.: Uromyces halstedii.
LEGUMINOSAE undet.: Ravenelia sessilis.
LEONTICE (Berberidaceae) robustum (Maxim.) Diels: Aecidium caulophylli.
LEPTODERMIS (Rubiaceae) glomerata Hutchinson, L. pilosa Diels, L. potanini Batalin: Coleosporium leptodermidis.
LESPEDEZA (Leguminosae), see also Campylotropis.
Lespedeza bicolor Turcz.: Uromyces lespedezae-bicoloris; Uromyces lespedezae-procumbentis.
Lespedeza chinensis G. Don, L. cuneata (Mont.) G. Don, L. daurica (Lam.) Schindl., L. floribunda Bunge, L. formosa Koehne, L. hedysaroides Kitagawa, L. juncea (L.) Pers: Uromyces lespedezae-procumbentis.

Lespedeza striata (Thunb.) H. & A.: Uromyces itoanus; Uromyces lespedezae-procumbentis.
Lespedeza stipulacea Maxim.: Uromyces itoanus.
Lespedeza tomentosa Sieb.: Uromyces lespedezae-procumbentis.
Lespedeza thunbergii (DC.) Nakai: Uromyces lespedezae-procumbentis.
Lespedeza yunnanensis Franch.: Uromyces rugulosus.
Lespedeza sp.: Uromyces lespedezae-procumbentis; Uromyces rugulosus.
LEUCAS (Labiatae) ciliata Benth.: Puccinia leucadis.
LEUCOTELIUM pruni-persicae (Hort) Tranz.: Prunus persica (1, 4, 31, 35, 38, 44).
LIGULARIA (Compositae) dictyoneura (Franch.) Hand.-Mazz., L. lapathifolius, L. sp.: Coleosporium ligulariae.
Ligularia sibirica (L.) Cass.: Puccinia expansa.
Ligularia speciosa F. & M.: Puccinia eriophori.
LIGUSTRUM (Oleaceae) ibota Sieb. & Zucc., L. lucidum Ait., L. quihoui Carr., L. sinensis Lour.: Aecidium klugkisteanum.
Ligustrum sp.: Aecidium klugkisteanum; Aecidium ligustricola.
LINDERA (Lauraceae) strychnifolia F. Vill.: Puccinia lauricola.
Lindera sp.: Puccinia coronopsora.
LINUM (Linaceae) usitatissimum L., L. sp.: Melampsora lini.
LITSEA (Lauraceae) populifolia Gamble: Aecidium sp.
Litsea sp.: Puccinia morata.
LOBELIA (Lobeliaceae) pyramidalis Wall.: Coleosporium campanulae.
Lobelia sp.: Coleosporium campanulae; Puccinia aucta.
LOLIUM (Gramineae) multiflorum Lam.: Puccinia coronata.
LOMATOGONIUM (Gentianaceae) bicoronatum: Puccinia lomatogonii.
LONICERA (Caprifoliaceae) japonica Thunb., L. maackii Maxim.: Puccinia festucae.
LUZULA (Juncaceae) multiflora Lej.: Puccinia obscura.
LYCHNIS (Caryophyllaceae) sp.: Uromyces crassivertex.
LYCOPUS (Labiatae) europaeus L.: Puccinia menthae.
LYSIMACHIA (Primulaceae) clethroides Duby: Puccinia dieteliana; Puccinia lysimachiae.
Lysimachia hui Diels: Puccinia limosae.
Lysimachia paradiformis Franch., L. trientaloides Hemsl., L. sp.: Puccinia dieteliana.
MAAKIA (Leguminosae) amurensis Rupr.: Uromyces amurensis.
MACHILUS (Lauraceae) bournei Hemsl.: Aecidium machili.
Machilus sp.: Puccinia machili; Puccinia machiliicola.
MAHONIA (Berberidaceae) fortunei (Lindl.) Fedde: Puccinia graminis.
Mahonia sheridaniana Schneid.: Gambleola cornuta.
MAINSIA chinensis (Diet.) Jacks., see Gerwasia chinensis.
MALLOTUS (Euphorbiaceae) sp.: Phakopsora malloti.
MALUS (Rosaceae) asiatica Nakai, see M. prunifolia.
Malus baccata (L.) Borkh., M. domesticus Bostch: Gymnosporangium yamadae.
Malus hupehensis (Pamp.) Rehd.: Gymnosporangium yamadae.
Malus kansuensis (Batal.) Schneid.: Gymnosporangium fenzelianum.
Malus prunifolia (Willd.) Borkh., M. pumila Mill.: Gymnosporangium yamadae.
Malus sieboldii (Reg.) Rehd.: Gymnosporangium leve.
Malus spectabilis (Ait.) Borkh., M. sp.: Gymnosporangium yamadae.
Malus theifera Rehd., see Malus hupehensis.
MARAVALIA achroa (Syd.) Arth. & Cumm.: Dalbergia sp. (4).
Maravalia hyalospora (Sawada) Diet., see Poliotelium hyalospora.
MAZUS (Scrophulariaceae) rugosum Lour., M. stachydifolius Maxim., M. sp.: Aecidium foetidum.
MEDICAGO (Leguminosae) lupulina L., M. sativa L.: Uromyces striatus.
MELAMPSORA aleuritidis Cumm.: Aleuritis sp. (4).
Melampsora apocyni Tranz.: Apocynum venetum (11).
Melampsora coleosporioides Diet.: Salix babylonica (1, 22, 35, 38); S. heteromera (31); S. mesneyi (4); S. matsudana (1, 23).
Melampsora confluens Jacks., see Melampsora ribesii-purpureae.
Melampsora cynanchi Thuem.: Cynanchum sibiricum (1).
Melampsora euphorbiae (Schub.) Cast.: Euphorbia esula (1, 44); E. lunulata (23); E. sp. (4).
Melampsora euphorbiae-dulcis Otth: Euphorbia chrysocoma (4); E. lunulata (1); E. pekinensis (4, 25); E. sieboldiana (44); E. sp. (4, 23, 35, 38).
Melampsora euphorbiae-lunulatae Liou & Wang: Euphorbia lunulata (1).

Melampsora farinosa Schroet.: Salix wilsonii (19).
Melampsora hypericorum Schroet.: Hypericum sampsoni (1, 35, 38).
Melampsora idesiae Miyabe: Idesia polycarpa (35, 38).
Melampsora kusanoi Diet.: Hypericum ascyron (1, 14); H. patulum (4, 31).
Melampsora larici-populina Kleb.: Populus italica (1); P. simonii (23); P. yunnanensis (31).
Melampsora larici-epitea Kleb.: Salix delavayana (31); S. longiflora (31); S. psilostigma (31); S. viminalis (14); S. sp. (4).
Melampsora lini (Ehrenb.) Lév.: Linum usitatissimum (1, 17, 22, 44).
Melampsora magnusiana G. Wagn.: Corydalis sp. (1); Populus davidiana (15).
Melampsora periplocae Miyake: Periploca sp. (1).
Melampsora ribesii-purpureae Kleb.: Ribes diacantha (1); Salix purpurea (23); S. wilsonii (1).
Melampsora ricini Pass.: Ricinus communis (31).
Melampsora rostrupii G. Wagn.: Populus alba (1); P. rotundifolia (31); P. tremula (1).
Melampsora salicis-albae Kleb.: Salix sp.: (22, 31).
Melampsora salicis-cavaleriei Tai: Salix cavaleriei (31).
Melampsora stellerae Teich: Stellera chamaejasme (28).
Melampsora yezoensis Miyabe & Matsum.: Salix longiflora (4).
Melampsora yoshinagai P. Henn.: Wikstroemia indica (1, 16, 44); W. sp. (35, 38).
MELAMPSORELLA caryophyllacearum Schroet.: Abies forrestii (19); Cerastium sp. (22); Pseudostellaria heterophylla (28).
Melampsorella cerastii Schroet., see Melampsorella caryophyllacearum.
Melampsorella itoana (Hirats. f.) S. Ito & Homma: Oxalis sp. (4).
MELAMPSORIDIUM alni (Thuem.) Diet.: Alnus cremastogene (22, 31).
Melampsoridium carpini (Fuck.) Diet.: Carpinus sp. (4).
Melampsoridium hiratsukanum S. Ito: Alnus hirsuta (10).
MELAMPYRUM (Scrophulariaceae) roseum Maxim.: Coleosporium melampyri.
MELICA (Gramineae) nutans L.: Puccinia melicae.
Melica onoci Franch. & Sav.: Puccinia coronata.
Melica sp.: Puccinia rangiferina.
MELILOTUS (Leguminosae) indicus All.: Uromyces baeumlerianus.
MELIOSMA (Sabiaceae) cuneifolia Franch.: Aecidium meliosmae-pungentis.
Meliosma kirkii Hemsl.: Aecidium meliosmae.
Meliosma myriantha Sieb. & Zucc., M. parviflora Lecomte: Aecidium meliosmae-myrianthae.
Meliosma oldhami Miq.: Aecidium meliosmae-myrianthae; Phakopsora meliosmae.
Meliosma simplicifolia Roxb.: Phakopsora meliosmae.
Meliosma stewardii Merr.: Aecidium meliosmae; Aecidium meliosmae-myrianthae.
Meliosma sp.: Aecidium meliosmae-myrianthae; Phakopsora meliosmae.
MELOTHRIA (Cucurbitaceae) indica Sour.: Puccinia arisanensis.
MENTHA (Labiatae) arvensis L., M. sachalinensis Briq., M. sp.: Puccinia menthae.
MERCURIALIS (Euphorbiaceae) leiocarpa Sieb. & Zucc.: Uromyces mercurialis.
MICROSTEGIUM (Gramineae) vimineum A. Camus: Puccinia polliniae.
MILESIA erythrosora Faull: Dryopteris sp. (31).
Milesia miyabei (Kamei) Faull: Dryopteris crassirhizoma (14).
MILESINA, see Milesia.
MILLETIA (Leguminosae) reticulata Benth.: Uromyces amurensis.
MISCANTHUS (Gramineae) japonicus Anderss.: Puccinia erythropus; Puccinia eulaliae.
Miscanthus sacchaliflorus Hack.: Puccinia miscanthi.
Miscanthus sacchariflorus (Maxim.) B. & H.: Puccinia miscanthi; Puccinia miscanthicola.
Miscanthus sinensis Anders.: Puccinia erythropus; Puccinia eulaliae; Puccinia miscanthi; Puccinia rufipes.
Miscanthus sp.: Puccinia erythropus; Puccinia eulaliae.
MIYAGIA anaphalidis Miyabe: Anaphalis sp. (5).
MOLINIA (Gramineae) sp.: Puccinia moliniicola.
MORUS (Moraceae) alba L.: Aecidium mori; Phakopsora fici-erecti.
Morus australis Poir.: Aecidium mori.
Morus sp.: Cerotelium fici.
MOSLA (Labiatae) lanceolata Maxim., M. punctata Maxim., M. sinensis Maxim., M. sp: Coleosporium perillae.
MUEHLENBECKIA (Polygonaceae) platyclados (F. Muell.) Meissn.: Puccinia muehlenbeckiae.
MUEHLENBERGIA (Gramineae) hugelii Trin.: Puccinia sinica.
MYRIPNOIS (Compositae) dioica Bunge: Phakopsora compositarum.

NEOLITSEA (Lauraceae) aurata (Hayata) Merr.: Xenostele neolitseae.
NEPETA (Labiatae), see Glecoma and Schizonepeta.
NOTHORAVENELIA japonica Diet.: Securinega fluggeoides (23, 25); S. suffruticosa (1, 14).
NYSSOPSORA cedrelae (Hori) Diet.: Cedrela sinensis (8, 13, 23, 24, 44); Spondias axillaris (31); Toona sp. (28).
Nyssopsora thwaitesii (Berk. & Br.) Syd.: Aralia elata (1, 18, 20); Brassaiopsis palmata (19).
OENANTHE (Umbelliferae) stolonifera DC., O. sp.: Puccinia oenanthes.
OPLISMENUS (Gramineae) undulatifolius Roem. & Schult.: Puccinia sp.
ORCHIDACEAE undet.: Coleosporium bletiae; Puccinia anhweiana; Puccinia nasuensis; Puccinia sinicensis.
ORCHIS (Orchidaceae) sp.: Puccinia anhweiana.
ORIGANUM (Labiatae) vulgare L., O. sp.: Puccinia menthae; Uredo sp.
ORYZA (Gramineae) sativa L.: Uromyces coronatus.
ORYZOPSIS (Gramineae) obtusa Stapf: Uredo sp.
OSMANTHUS (Oleaceae) fragrans Lour.: Aecidium osmanthi.
OXALIS (Oxalidaceae) corniculata L.: Puccinia sorghi.
Oxalis sp.: Melampsorella itoana.
OXYTROPIS (Leguminosae) herta: Uromyces punctatus (12).
Oxytropis sp.: Uromyces lapponicus.
PACHYRHIZUS (Leguminosae) bulbosus Britt.: Phakopsora pachyrhizi.
PAEDERIA (Rubiaceae) chinensis Hance, see Paederia scandens.
Paederia foetida L.: Coleosporium paederiae; Puccinia zoysiae; Uredo paederiae.
Paederia scandens (Lour.) Merr.: Puccinia zoysiae.
Paederia tomentosa Maxim., see Paederia scandens.
Paederia sp.: Coleosporium paederiae; Puccinia zoysiae.
PAEONIA (Ranunculaceae) albiflora Pall.: Aecidium paeoniae Kom.; Cronartium flaccidum.
PALIURUS (Rhamnaceae) hemsleyanus Rehd., P. sp.: Puccinia coronata.
Paliurus ramosissimus Poir.: Phakopsora zizyphi-vulgaris.
PANAX (Araliaceae) pseudo-ginsing Wall.: Uredo panacis.
PANICUM (Gramineae) repens L.: Uromyces linearis.
Panicum sp.: Puccinia pangasinensis.
PARTHENOCISSUS (Vitaceae) heterophylla (Thunb.) Merr.: Phakopsora ampelopsidis.
PASPALUM (Gramineae) sp.: Puccinia paspalina.
PATRINIA (Valerianaceae) heterophylla Bunge, P. sp.: Puccinia patriniae.
Patrinia scabiosaefolia Link, P. scabra Bunge: Puccinia hemerocallidis.
PEDICULARIS (Scrophulariaceae) cyathophylla Franch.: Coleosporium euphrasiae.
Pedicularis deltoides Franch., P. gracilis Wall., P. racemosa Dougl.: Coleosporium pedicularidis.
PERIDERMIUM corruscans Fries, see Chrysomyxa ledi.
Peridermium pini (Willd.) Lév.: Pinus sp. (1).
PERILLA (Labiatae) frutescens Britt., P. nankinensis Dcne., P. ocymoides L., P. puteaceus (L.) Britt.: Coleosporium perillae.
PERIPLOCA (Asclepiadaceae) sp.: Melampsora periplocae.
PERSEA (Lauraceae) sp.: Puccinia scimitriformis.
PERSICARIA (Polygonaceae), see Polygonum.
PEUCEDANUM (Umbelliferae) decursivum Maxim., see Angelica decursiva.
Peucedanum terebinthinaceum Fisch.: Puccinia bullata.
Peucedanum sp.: Puccinia nanbuana.
PHAENOSPERMA (Gramineae) sp.: Puccinia sp.
PHAKOPSORA ampelopsidis Diet. & Syd.: Ampelopsis brevipedunculata (44), A. japonica (1, 4); Parthenocissus heterophylla (24); Vitis betulifolia (22, 31); V. pentagona (4); V. vinifera (16, 31); V. sp. (44).
Phakopsora artemisiae Hirats. f.: Artemisia dracunculus (31); A. vulgaris (23, 44); A. sp. (1, 4); Aster sp. (4); Chrysanthemum indicum (1, 44); C. sp. (4).
Phakopsora cheoana Cumm.: Cedrela sinensis (4).
Phakopsora cingens (Syd.) Hirats. f.: Bridelia monoica (1, 33, 44); Flueggia sp. (16).
Phakopsora compositarum Miyake: Artemisia sacrorum (23); A. vulgaris (23); Aster hispidus (23); A. sp. (1); Chrysanthemum indicum (23); C. sibiricum (23); Myripnois dioica (23); Saussurea pectinata (23).
Phakopsora desmium (Berk. & Br.) Cumm.: Gossypium barbadense (31); G. sp. (40).
Phakopsora ehretiae Hirats. f.: Ehretia sp. (16).

Phakopsora elephantopodis Hirats. f.: Vernonia patula (16).
Phakopsora fici-erecti Ito & Otani: Ficus sp. (4); Morus alba (4).
Phakopsora formosana Syd.: Glochidion sp. (4, 35, 38).
Phakopsora glochidii (Syd.) Arth.: Glochidion sp. (16, 33, 44).
Phakopsora hengshanensis Tai: Ficus heteromorpha (31); F. martini (31).
Phakopsora incompleta (Syd.) Cumm.: Andropogon sp. (4); Eulalia sp. (4).
Phakopsora malloti Cumm.: Mallotus sp. (4).
Phakopsora meibomiae Arth.: Desmodium racemosum (4).
Phakopsora meliosmae Kusano: Meliosma oldhami (4); M. simplicifolia (4).
Phakopsora pachyrhizi Syd.: Glycine max (1, 4, 14, 17, 22, 31, 40); Pachyrhizus bulbosum (22, 31); Pueraria thunbergiana (4); Shuteria sp. (4); Vigna sinensis (1).
Phakopsora punctiformis (Barcl. & Diet.) Diet.: Galium aparine (4); G. asperifolium (31).
Phakopsora tecta Jacks. & Holw.: Commelina nudiflora (16).
Phakopsora vitis (Thuem.) Syd., see Phakopsora ampelopsidis.
Phakopsora zizyphi-vulgaris Diet.: Paliurus ramosissimus (22); Zizyphus jujuba (1, 4, 23, 25, 31, 35, 38, 44); Z. spinosa (44).
PHALARIS (Gramineae) arundinacea L.: Puccinia sessilis.
PHASEOLUS (Leguminosae) angularis Wight, P. aureus Roxb., P. chrysantha Savi, P. coccinea L., P. mungo L., P. radiatus L., P. vulgaris L.: Uromyces phaseoli.
PHEGOPTERIS (Polypodiaceae) polypodioides Fee: Uredinopsis filicina.
PHELLODENDRON (Rutaceae) amurensis Rupr., P. sachalinensis Sarg.: Coleosporium phellodendri.
PHELLOPTERUS (Umbelliferae) littoralis (A. Gray) Benth.: Puccinia phellopteri.
PHOTINIA (Rosaceae) amphidoxa (Schneid.) Rehd. & Wils., P. parvifolia (Pritz.) Schneid.: Gymnosporangium japonicum.
Photinia serrulata Lindl.: Gymnosporangium wenshanense.
Photinia subumbellata Rehd. & Wils., see Photinia parvifolia.
Photinia villosa (Thunb.) DC.: Gymnosporangium japonicum.
PHRAGMIDIUM brevipedicellatum Hirats. f.: Potentilla kleiniana (14, 31).
Phragmidium disciflorum (Tode) James: Rosa cymosa (44); R. davidii (33); R. multiflora (1); R. odorata (31); R. rugosa (1, 33, 44); R. sempervirens (22); R. sp. (1, 4, 19).
Phragmidium fragariastri (DC.) Schroet.: Potentilla flagellaris (1).
Phragmidium fusiforme Schroet.: Rosa glomerata (19).
Phragmidium griseum Diet.: Rubus crataegifolius (1); R. morifolius (1); R. sp. (4).
Phragmidium handelii Petrak: Rosa glomerata (28).
Phragmidium kamtschatkae (Anders.) Arth. & Cumm.: Rosa acicularis (33); R. davurica (1).
Phragmidium montivagum Arth.: Rosa davurica (1).
Phragmidium mucronatum (Fries) Schlecht., see Phragmidium disciflorum.
Phragmidium okianum Hara: Rubus sp. (1, 9).
Phragmidium nanbuanum Diet.: Rubus sp. (4).
Phragmidium papillatum Diet.: Potentilla cryptotaenia (1); P. tanacetifolia (14).
Phragmidium pauciloculare (Diet.) Syd.: Rubus parvifolius (16, 31, 35, 38); R. rosaefolius (31); R. subornatus (31); R. triphyllus (1); R. sp. (1, 22).
Phragmidium potentillae (Pers.) Karst.: Potentilla anserina (1); P. chinensis (1, 14, 25, 33, 44); P. conferta (28); P. discolor (15); P. fragarioides (23); P. ornithopoda (28); P. paradoxia (15;) P. sericea (33); P. supina (1); P. tanacetifolia (33); P. verticellata (33); P. verticillaris (28); P. viscosa (33); P. sp. (1, 4).
Phragmidium receptaculorum Wei: Rosa sp. (22).
Phragmidium rosae-dauricae Miura: Rosa davurica (1); R. sp. (4).
Phragmidium rosae-multiflorae Diet.: Rosa chinensis (1, 44); R. multiflora (1, 33, 35, 38, 44).
Phragmidium rosae-rugosae Kasai: Rosa omeiensis (31); R. rugosa (1).
Phragmidium rubi-parvifolii Liou & Wang: Rubus idaeus (33); R. parvifolius (1, 25, 33, 44).
Phragmidium rubi-thunbergii Kusano: Rubus thunbergii (1, 35, 38); R. sp. (4).
Phragmidium shensianum Tai & Cheo: Rubus idaeus (33).
Phragmidium sikangense Petrak: Rubus pungens (28).
Phragmidium sinicum Tai & Cheo: Rubus crataegifolius (33).
Phragmidium tuberculatum Mueller: Rosa sp. (22).
Phragmidium violaceum (Schultz) Wint.: Rubus sp. (1).
Phragmidium yezoense Kasai: Rosa rugosa (35, 38). According to Hiratsuka (Jap. Jour. Bot. 7: 256. 1935) this record probably represents P. montivagum.
Phragmidium sp.: Rosa cymosa (22).

PHRAGMITES (Gramineae) communis Trin.: Puccinia magnusiana; Puccinia moriokaensis; Puccinia okatamaensis; Puccinia phragmites.
Phragmites karka (Retz.) Trin.: Puccinia invenusta.
Phragmites longivalvis Steud.: Puccinia magnusiana.
Phragmites vulgaris (Lam.) Crep., see P. communis.
Phragmites sp.: Puccinia longinqua; Puccinia moriokaensis.
PHYLLANTHUS (Euphorbiaceae) flexuosus Muell.: Aecidium phyllanthi.
PHYLLOSTACHYS (Gramineae) puberula Munro: Puccinia melanocephala; Stereostratum corticioides.
Phyllostachys sp.: Puccinia longicornis; Puccinia melanocephala; Puccinia phyllostachydis; Stereostratum corticioides.
PHYSOPELLA sinensis Syd., see Uredo sinensis.
PICEA (Pinaceae) likiangensis (Franch.) Pritz.: Chrysomyxa ledi.
PILEOLARIA cotini-coggyriae Tai & Cheo: Cotinus coggyria (33).
Pileolaria dieteliana Syd.: Rhodotypus scandius (1).
Pileolaria extensa Arth.: Pistacia chinensis (35, 38). This report is undoubtedly incorrect since P. extensa has been collected only in North America and only on the genus Rhus.
Pileolaria klugkistiana Diet.: Rhus chinensis (1, 33, 35, 38, 44); R. potaninii (33); R. punjabensis (4).
Pileolaria pistaciae Tai & Wei: Pistacia chinensis (1, 8, 25, 35, 38, 44).
Pileolaria shiraiana (Diet. & Syd.) S. Ito: Rhus delayavi (31); R. sylvestris (1, 44); R. verniciflua (44); R. sp. (4, 16, 35, 38).
Pileolaria terebinthi (DC.) Cast.: Pistacia chinensis (35, 38); P. weinmannifolia (8, 31).
PINUS (Pinaceae) massoniana Lamb.: Coleosporium asterum; Cronartium quercuum.
Pinus yunnanensis Franch.: Cronartium flaccidum.
Pinus sp.: Peridermium pini.
PISTACIA (Anacardiaceae) chinensis Bunge: Pileolaria extensa; Pileolaria pistaciae; Pileolaria terebinthi.
Pistacia weinmannifolia Poiss., P. sp.: Pileolaria terebinthi.
PISUM (Leguminosae) sativum L.: Uromyces pisi.
PLATYCODON (Campanulaceae) sp.: Coleosporium campanulae.
PLECTRANTHUS (Labiatae) bulleyanus Diels, P. coesta Buch.-Ham., P. eriocalyx Dunn: Coleosporium plectranthi.
Plectranthus glaucocalyx Maxim.: Aecidium plectranthi; Coleosporium plectranthi.
Plectranthus inflexus Vahl, P. nervosus Hemsl., P. phyllopodus, P. racemosus Hemsl., P. sculponeatus Vaniot, P. striatus Benth.: Coleosporium plectranthi.
PLEUROPTEROPYRUM (Polygonaceae), see Polygonum.
POA (Gramineae) annua L., P. sp.: Puccinia poae-sudeticae.
Poa ocroleuca Steud.: Puccinia poarum.
Poa pratensis L.: Puccinia poae-pratensis; Puccinia poae-sudeticae.
POGONATHERUM (Gramineae) sp.: Puccinia pogonatheri.
POLIOTELIUM hyalospora (Sawada) Mains: Acacia confusa (1, 16, 44).
POLLIA (Commelinaceae) sp.: Uromyces commelinae.
POLYGONATUM (Liliaceae) sp.: Aecidium dispori; Puccinia smilacinae.
POLYGONUM (Polygonaceae) amphibium L.: Puccinia polygoni-amphibii.
Polygonum aviculare L.: Uromyces polygoni.
Polygonum bistorta L.: Puccinia bistortae; Puccinia cari-bistortae.
Polygonum caespitosum Blume: Puccinia benokiyamensis; Puccinia polygonicola.
Polygonum campanulatum Hook. f.: Puccinia kweichowana.
Polygonum capitatum Buch.-Ham.: Puccinia fagopyri.
Polygonum chinense L.: Puccinia benokiyamensis; Puccinia congesta; Puccinia polygonicola.
Polygonum convolvulus L.: Puccinia polygoni-amphibii.
Polygonum cuspidatum Sieb. & Zucc.: Aecidium polygoni-cuspidatae; Puccinia polygoni-amphibii.
Polygonum cymosum Roxb.: Puccinia fagopyri; Puccinia yunnanensis.
Polygonum dielsii Levl.: Puccinia congesta.
Polygonum divaricatum L.: Puccinia calumnata; Puccinia mammillata; Puccinia nitidula.
Polygonum dumetorum L.: Puccinia polygoni-amphibii.
Polygonum fagopyrum L., see Fagopyrum esculentum.
Polygonum lapathifolium L.: Puccinia polygoni-lapathifolii; Puccinia polygoni-weyrichii.
Polygonum longisetum De Bruyn: Puccinia polygoni-amphibii.
Polygonum multiflorum Thunb.: Puccinia polygoni-amphibii; Uromyces polygoni.

Polygonum nepalense Meissn.: Puccinia benokiyamensis; Puccinia polygonicola.
Polygonum paleaceum Wall.: Puccinia taliensis.
Polygonum perfoliatum L., P. sagittatum L., P. sieboldi Ohki, P. thunbergii Sieb. & Zucc.: Puccinia polygoni-amphibii.
Polygonum viviparum L.: Puccinia taliensis.
Polygonum sp.: Aecidium polygoni-cuspidatae; Puccinia benokiyamensis; Puccinia congesta; Puccinia polygoni-amphibii; Puccinia polygoni-weyrichii.
POLYPODIUM (Pteridophyta) veitchii Bak.: Hyalopsora sp.
POLYPOGON (Gramineae) lutosus Hitchc.: Puccinia coronata.
POPULUS (Salicaceae) alba L.: Melampsora rostrupii.
Populus davidiana Dode: Melampsora magnusiana.
Populus italica L.: Melampsora larici-populina.
Populus nigra L.: Uredo tholopsora.
Populus rotundifolia Griff.: Melampsora rostrupii.
Populus simonii Carr.: Melampsora larici-populina.
Populus tomentosa Carr.: Uredo tholopsora.
Populus tremula L.: Melampsora rostrupii.
Populus yunnanensis Dode: Melampsora larici-populina.
POTENTILLA (Rosaceae) anserina L., P. chinensis Ser., P. conferta Bunge: Phragmidium potentillae.
Potentilla cryptotaenia Maxim.: Phragmidium papillatum.
Potentilla discolor Bunge: Phragmidium potentillae.
Potentilla flagellaris Willd.: Phragmidium fragariastri.
Potentilla fragarioides L.: Phragmidium potentillae; Pucciniastrum potentillae; Uredo nervicola.
Potentilla kleiniana Wight & Arn.: Phragmidium brevipedicellatum.
Potentilla multifida L.: Pucciniastrum potentillae.
Potentilla ornithopoda Tausch, P. paradoxia Nutt., P. sericea L., P. supina L.: Phragmidium potentillae.
Potentilla tanacetifolia Willd: Phragmidium papillatum; Phragmidium potentillae.
Potentilla verticillaris Steph., P. viscosa Don, P. sp.: Phragmidium potentillae.
POTERIUM (Rosaceae) canadense A. Gray: Xenodochus carbonarius.
PRENANTHES (Compositae) tatarinowii Maxim.: Puccinia orbicula.
Prenanthes sp.: Puccinia prenanthes-purpureae.
PRUNUS (Rosaceae) cerasus L.: Caeoma makinoi.
Prunus glandulosus Thunb.: Tranzschelia pruni-spinosae.
Prunus mandshurica (Maxim.) Koehne: Caeoma makinoi; Tranzschelia pruni-spinosae.
Prunus persica (L.) Batsch: Leucotelium pruni-persicae; Tranzschelia pruni-spinosae.
Prunus salicina Lindl.: Tranzschelia pruni-spinosae.
Prunus sp.: Caeoma makinoi; Leucotelium pruni-persicae; Thekopsora aerolata; Tranzschelia pruni-spinosae.
PSEUDOSTELLARIA (Caryophyllaceae) heterophylla (Miq.) Pax.: Melampsorella caryophyllacearum.
PTERIDIUM (Polypodiaceae) aquilinum (L.) Kuhn: Uredinopsis kameiana; Uredinopsis pteridis.
PUCCINIA absinthii DC.: Artemisia annua (1); A. capillaris (1, 25, 34); A. desertorum (1); A. dubia (31); A. japonica (31); A. mongolica (31); A. sacrorum (1, 15, 25); A. sieversiana (1); A. vulgaris (1); A. sp. (5, 14, 35, 38).
Puccinia abutili Berk. & Br.: Abutilon gebauerianum (31).
Puccinia acetosae (Schum.) Koern.: Rumex dentatus (31); R. sp. (5).
Puccinia achroa Syd.: Elaeagnus sp. (35, 38).
Puccinia adenophorae Diet.: Adenophora remotifolia (1).
Puccinia adenophorae-verticillatae Ito & Terni: Adenophora jasionifolia (28).
Puccinia adjuncta Mitter: Artemisia sp. (5).
Puccinia aequitatis Cumm.: Benzoin sp. (3).
Puccinia aestivalis Diet.: Arthraxon lanceolatum (5).
Puccinia agropyri-ciliaris Tai & Wei: Agropyron ciliare (1, 14, 44).
Puccinia agropyri Ellis & Ev., see Puccinia rubigo-vera.
Puccinia agrostidicola Tai: Agrostis sp. (31).
Puccinia ainsliaeae Syd.: Ainsliaea hui (24).
Puccinia allii (DC.) Rud.: Allium bakeri (1); A. fistulosum (1, 17, 40); A. longistilum (25); A. odorum (1); A. scorodoprasum (5); A. sp. (44).

Puccinia angelicae-edulis Miyabe, see Puccinia nanbuana.
Puccinia angelicicola P. Henn.: Angelica miqueliana (1).
Puccinia angustata Peck: Cyperus iria (1).
Puccinia anhweiana Cumm.: Orchis sp. (5).
Puccinia anomala Rostr., see Puccinia hordei Otth not Fuck.
Puccinia aomoriensis Syd.: Atractylodes chinensis (1, 14); A. ovata (1, 23, 25, 44); Carex lanceolata (1); C. pisiformis (1).
Puccinia arachidis Speg.: Arachis hypogoea (1).
Puccinia arenariae (Schum.) Wint.: Dianthus chinensis (1, 44); Stellaria chinensis (24); S. paniculata (31); S. saxatilis (31).
Puccinia arisanensis Hirats. f.: Melothria indica (1, 31).
Puccinia argentata (Schultz) Wint.: Adoxa moschatellina (1); Impatiens nolitangere (14); I. sp. (8, 33, 44).
Puccinia aristolochiae (DC.) Wint.: Aristolochia sp. (1).
Puccinia artemisiae-keiskiana Miura: Artemisia frigida (1); Artemisia keiskiana (1).
Puccinia artemisiella Syd.: Artemisia vulgaris (1).
Puccinia arthraxonis (P. Henn.) Syd. & Butl.: Arthraxon hispidus (22); A. sp. (31).
Puccinia arundinellae Barcl.: Arundinella anomala (1); A. nepalensis (31); A. setosa (31); A. sp. (8).
Puccinia arundinellae-anomalae Diet.: Arundinella anomala (1, 14, 22, 25, 31, 35, 38, 44).
Puccinia arundinellae-setosae Tai: Arundinella setosa (31); Sporobolus indicus (22, 31).
Puccinia asaricola Tai & Cheo: Asarum sp. (33, 44).
Puccinia asparagi-lucidi Diet.: Asparagus sp. (5, 44).
Puccinia atrofusca (Dudl. & Thomp.) Holw.: Artemisia laciniata (1); A. vulgaris (1); Carex stenophylla (1).
Puccinia atropuncta Peck & Clint.: Veratrum nigrum (1, 28, 33).
Puccinia aucta Berk. & Muell.: Lobelia sp. (1).
Puccinia australis Koern.: Diplachne serotina (35, 38, 44); Sedum spinosum (1); S. telephium (1, 35, 38).
Puccinia bardanae Corda: Arctium majus (5).
Puccinia baryi (Berk. & Br.) Wint.: Brachypodium sylvaticum (31).
Puccinia behenis Otth: Cucubalus baccifer (31); Silene sp. (1).
Puccinia belamcandae Diet.: Belamcanda chinensis (1, 25, 44).
Puccinia benokiyamensis Hirats. f.: Polygonum caespitosum (5); P. chinense (5, 16); P. nepalense (5).
Puccinia bistortae (Strauss) DC.: Polygonum bistorta (1, 33, 37).
Puccinia bolleyana Sacc.: Sambucus racemosa (1); S. sieboldiana (23). The telia stage on species of Carex has not been recognized in China.
Puccinia brachybotrydis Kom.: Brachybotrys paridifolius (1, 14, 18).
Puccinia brachysora Diet.: Brachypodium sp. (1).
Puccinia bullata (Pers.) Wint.: Peucedanum terebinthinaceum (25); Seseli condensatum (28).
Puccinia bupleuri Rud.: Bupleurum falcatum (1, 33); B. longeradiatum (14).
Puccinia bupleuri-falcatae Wint., see Puccinia bupleuri.
Puccinia cacao McAlp.: Hemarthria compressa (22); Rottboellia compressa (1, 31, 44); R. sp. (5, 35, 38).
Puccinia calthae Link: Caltha palustris (1, 18).
Puccinia calthaecola Schroet.: Caltha membranacea (14).
Puccinia calumnata Syd.: Polygonum divaricatum (15, 33).
Puccinia campanumaeae Pat.: Campanumaea sp. (1).
Puccinia canaliculata (Schw.) Lagerh.: Cyperus sp. (35, 38).
Puccinia cara Cumm.: Benzoin sp. (3).
Puccinia carduorum Jacky: Carduus acanthoides (1); C. crispus (14).
Puccinia cari-bistortae Kleb.: Polygonum bistorta (25).
Puccinia caricina DC.: Sceptroenide sp. (28). This is probably the aecial stage of Puccinia caricis.
Puccinia caricis (Schum.) Schroet.: Carex brunnea (1); C. cruciata (31); C. filicina (22); C. lanceolata (1); C. vesicaria (1); C. sp. (35, 38); Ribes diacantha (1); R. fasciculatum (1, 35, 38); R. mandschuricum (1); Urtica dioica (1). See also Puccinia caricina and Aecidium girardiniae.
Puccinia caricis-asteris Arth., see Puccinia extensicola.
Puccinia caricis-brunneae Diet.: Carex brunnea (1).
Puccinia caricis-filicinae Barcl.: Carex filicina (35, 38).

Puccinia caricis-gibbae Diet.: Carex sp. (5, 35, 38).
Puccinia caricis-montanae Ed. Fisch.: Carex nubigena (1).
Puccinia caricis-siderostictae (P. Henn.) Diet.: Carex siderosticta (1).
Puccinia carthami Corda: Carthamus tinctorius (31).
Puccinia cesatii Schroet.: Andropogon annulatus (22, 31); A. ischaemum (1, 35, 38).
Puccinia chrysanthemi Roze: Chrysanthemum indicum (22, 24, 28); C. sibiricum (1); C. zawadzkii (14); C. sp. (5).
Puccinia chrysosplenii Grev.: Chrysosplenium alternifolium (1, 18); C. griffithii (28).
Puccinia cicutae Lasch: Cicuta virosa (15).
Puccinia cinnamomi Tai: Cinnamomum sp. (22, 31).
Puccinia cinnamomicola Cumm.: Cinnamomum sp. (3).
Puccinia circaeae Pers.: Circaea cordata (28); C. imaicola (31).
Puccinia circaeae-caricis Hasler: Circaea imaicola (31).
Puccinia cirsii Lasch: Cirsium arvense (44); S. segetum (1).
Puccinia cirsii-maritimi Diet.: Cirsium chinense (5).
Puccinia citrina Syd.: Smilax gaudichaudiana (1, 42); Smilax sp. (8, 35, 38).
Puccinia clematidicola Tai: Clematis connata (31).
Puccinia colletiana Barcl.: Rubia cordifolia (1).
Puccinia congesta Berk. & Br.: Polygonum chinense (1); P. dielsii (31); P. sp. (5).
Puccinia constata Syd.: Carex baccans (31).
Puccinia convolvuli (Pers.) Cast.: Calystegia hederacea (1, 5, 22, 23, 31); C. japonica (1); C. soldanella (1); C. subvolubilis (14).
Puccinia coronata Corda: Agropyron ciliare (1); Agrostis sp. (1, 35, 38); Arundinella arundinaceae (5); Avena sativa (1, 14, 17, 22, 31); Beckmannia syzygachne (31); Berchemia racemosa (1); B. sp. (1, 5, 31, 35, 38); Brachypodium sylvaticum (31); B. sp. (35, 38); Bromus ciliatus (31); B. sp. (1, 5, 44); Calamagrostis arundinacea (5); C. epigejos (1, 44); C. sp. (5, 22, 31, 35, 38); Deyeuxia sylvatica (1, 44); Glyceria aquatica (1); G. sp. (1, 35, 38); Hierochloa glabra (1); Lolium multiflorum (1); Melica onoci (23); Paliurus hemsleyanus (1); P. sp. (35, 38); Polypogon lutosus (22); Rhamnella martini (1); R. obovalis (19, 25, 44); R. sp. (35, 38); Rhamnus crenatus (1, 22, 44); R. globosa (1, 23, 25, 44); R. japonica (1, 44); R. kulingensis (1, 44); R. leptophylla (31); R. parvifolia (1, 23); R. utilis (1, 25); R. sp. (1, 5, 31, 35, 38).
Puccinia coronopsora Cumm.: Lindera sp. (3).
Puccinia corylopsidis Cumm.: Corylopsis sp. (5).
Puccinia crepidis Schroet.: Crepis tectorum (14).
Puccinia crepidis-japonicae (Lindr.) Diet.: Crepis japonica (22).
Puccinia cynodontis Lacroix: Cynodon dactylon (1, 16, 21, 31, 35, 38, 44).
Puccinia cyperi Arth.: Cyperus glomerata (1); C. iria (1); C. sp. (5, 35, 38, 44).
Puccinia cyperi-tagetiformis Kern: Cyperus sp. (44).
Puccinia delavayana Pat. & Har.: Salvia sp. (27).
Puccinia deyeuxiae Tai & Cheo: Deyeuxia sylvatica (33).
Puccinia diarrhenae Miyabe & Ito: Diarrhena manshurica (1).
Puccinia dieteliana Syd.: Lysimachia clethroides (1, 5, 8, 14, 24, 31); L. paradiformis (5); L. trientaloides (19); L. sp. (8, 14, 19, 33, 35, 38).
Puccinia dioicae Magn.: Carex sp. (1); Cirsium sp. (1, 44).
Puccinia dioscoreae Kom.: Dioscorea acerifolia (1); D. nipponica (14); D. quinqueloba (18, 20, 33).
Puccinia diplachnicola Diet.: Diplachne serotina: (1, 22, 33, 35, 36, 44).
Puccinia diplachnis Arth.: Diplachne sp. (1). This is a synonym of P. bartholomaei but the identity of the Chinese rust is uncertain.
Puccinia dispersa Erikss. & Henn., see Puccinia rubigo-vera.
Puccinia dispori Syd.: Disporum sp. (5).
Puccinia duthiae Ellis & Tracy: Andropogon sp. (31); Bothriochloa pertusa (22).
Puccinia elaeagni Yosh.: Elaeagnus lanceolatus (5).
Puccinia elymi Westend., see Puccinia rubigo-vera.
Puccinia elymina Miura: Elymus sibiricus (1).
Puccinia elytrariae P. Henn.: Justicia procumbens (1, 16).
Puccinia emaculata Schw.: Eragrostis ferruginea (1). This is a Panicum rust. Perhaps the record should be referred to Puccinia eragrostidis-ferrugineae.
Puccinia epigejos S. Ito: Calamagrostis epigejos (1, 14).

Puccinia epilobii-tetragoni Wint.: Epilobium sp. (19).
Puccinia epimedii Miyabe & Ito: Epimedium sp. (21, 33, 35, 38).
Puccinia eragrostidis-ferrugineae Tai: Eragrostis ferruginea (31).
Puccinia erebia Syd.: Clerodendron inerme (1, 16, 35, 38).
Puccinia eriophorae Thuem.: Ligularia speciosa (1).
Puccinia erythraeensis Pazschke: Andropogon micranthus (31); Capillipedum parviflorum (22).
Puccinia erythropus Diet.: Miscanthus japonicus (31); M. sinensis (5, 35, 38).
Puccinia eulaliae Barcl.: Erianthus fastigiatus (31); Miscanthus japonicus (31); M. sinensis (1, 22, 31, 35, 38, 44); M. sp. (1, 5, 31); Saccharum sp. (31); Sorghum vulgare (31). This is a rust of uncertain identity. The records on Sorghum and Saccharum, at least, are probably erroneous.
Puccinia expansa Link: Ligularia sibirica (33).
Puccinia extensicola Plowr.: Aster harrowianus (19); A. scaber (1); A. trinervis (1, 35, 38).
Puccinia fagopyri Barcl.: Fagopyrum esculentum (1, 35, 38, 44); Polygonum capitatum (31); P. cymosum (31).
Puccinia ferruginea Lév.: Smilax china (1, 8, 16, 22, 42, 44); S. davidiana (42); A. gaudichaudiana (31); S. glauca-china (42); S. longipes (31); S. sp. (31, 35, 38).
Puccinia ferruginosa Syd.: Artemisia japonica (22); A. vulgaris (1, 44).
Puccinia festucae Plowr.: Festuca extremiorientalis (15); Lonicera japonica (1, 35, 38); L. maakii (1, 44).
Puccinia festucae-ovinae Tai: Festuca ovina (31).
Puccinia filipodia Cumm.: Heteropogon contortus (22, 31).
Puccinia fimbristylis Arth.: Fimbristylis sp. (5).
Puccinia fraxini Kom., see Uropyxis fraxini.
Puccinia funkiae Diet.: Hosta coerulea (1, 5).
Puccinia fushunensis Hara: Leersia oryzoides (1).
Puccinia fusispora Syd.: Boehmeria sp. (5); Urtica angustifolia (1, 18).
Puccinia gentianae (Strauss) Link: Gentiana macrophylla (1); G. wutaiensis (28).
Puccinia glechomatis DC.: Glecoma hederacea (1, 7, 14); G. sp. (5).
Puccinia glumarum (Schmidt) Eriks. & Henn.: Agropyron ciliare (1, 22, 44); A. semicostatum (22, 28); Hordeum jubatum (15); H. vulgare (1, 22, 31, 44); Triticum aestivum (1, 22, 31, 44); T. vulgare (17, 38).
Puccinia glycyrrhizae Tai: Glycyrrhiza apera (31).
Puccinia graminis Pers.: Agropyron ciliare (1, 44); Avena sativa (14, 17, 39); Berberis acuminata (21); B. amurensis (14, 21); B. dielsiana (21); B. gagnepainii (21, 22); B. gilgiana (1); B. henryana (21, 22); B. julianae (21); B. levis (21, 22); B. poiretii (23); B. pruinosa (21, 23); B. sargentiana (21, 22); B. silva-taroucana (21, 22); B. virgetorum (1, 21, 44); B. wilsoniae (21, 22); Epimedium sp. (1); Hordeum vulgare (1, 22, 31, 44); Mahonia fortunei (21, 22, 31); Secale cereale (17); Triticum aestivum (1, 22, 31); T. vulgare (14, 17, 38).
Puccinia grossulariae Lagerh., see Puccinia caricis.
Puccinia gypsophilae Liou & Wang: Gypsophila oldhamiana (25, 44); G. pacifica (14).
Puccinia haleniae Arth. & Holw.: Halenia sibirica (1, 28).
Puccinia halorrhagidis Syd.: Halorrhagis micrantha (1).
Puccinia hashiokai Hirats.: Epipremnum mirabile (16).
Puccinia helianthi Schw.: Helianthus annuus (1, 14, 17, 22, 25, 31, 35, 38, 39, 44); H. tuberosus (5, 8).
Puccinia hemerocallidis Thuem.: Hemerocallis citrina (1, 23, 35); H. dumortieri (1); H. flava (1, 44); H. fulva (1, 19); H. minor (1, 14, 25); H. sp. (8, 31, 35, 38); Patrinia scabiosaefolia (1); P. scabra (23, 28).
Puccinia henryana Syd.: Smilax menispermoides (1); S. sp. (8, 35, 38).
Puccinia heterospora Berk. & Curt.: Abulilon theophrasti (31); A. sp. (35, 38), Sida glutinosa (1); S. veronicaefolia (1, 44); S. sp. (16).
Puccinia hieracii (Schum.) Mart.: Atractylodes ovata (1); Hieracium umbellatum (1, 14, 25, 33); Taraxacum heterolepis (14); T. mongolicum (1, 28); T. officinale (5, 14); T. sinensis (33).
Puccinia hierochloae S. Ito: Calamagrostis sp. (1); Hierochloa odorata (1).
Puccinia himalayensis (Barcl.) Diet., see Puccinia coronata (1).
Puccinia hordei Otth: Hordeum vulgare (1, 16, 17, 22, 31, 35, 38, 39, 44); H. sp. (5).
Puccinia horiana P. Henn.: Chrysanthemum indicum (1, 44).
Puccinia hsinganensis Miura: Fritillaria dagana (1).

Puccinia hyalina Diet.: Carex sp. (35, 38).
Puccinia ignava Arth., see Uredo ignava.
Puccinia impatientis-uliginosae Tai: Impatiens uliginosa (31).
Puccinia invenusta Syd.: Phragmites karka (31).
Puccinia iridis Wallr.: Iris dichotoma (1, 14); I. ensata (1, 31); I. japonica (22); I. setosa (1); I. tectorum (1); I. sp. (5, 37).
Puccinia ishikawa S. Ito, see Puccinia pygmaea.
Puccinia juncelli Diet.: Cyperus serotinus (31).
Puccinia junci (Strauss) Wint.: Juncus gracillimus (14).
Puccinia kuehnii Butl.: Saccharum arundinaceum (1, 44); S. narenga (38); S. spontaneum (31); S. sp. (5, 35).
Puccinia kusanoi Diet.; Arundinaria sp. (44); Deutzia sp. (1).
Puccinia kwangsiana Cumm.: Saussurea sp. (5).
Puccinia kwangsiensis Tai: Bambusa sp. (22, 31).
Puccinia kweichowana Cumm.: Polygonum campanulatum (5).
Puccinia kyllingae-brevifoliae Miura: Kyllinga brevifolia (22).
Puccinia lactucae Diet., see Puccinia minussensis. The species has also been recorded on Solidago virgaurea (1) but obviously in error.
Puccinia lactucae-debilis Diet.: Lactuca debilis (31).
Puccinia lactucae-denticulatae Diet.: Lactuca denticulata (1, 23, 44); L. indica (1); L. sonchifolia (34).
Puccinia lactucae-repentis Miyabe & Miyake: Lactuca chinensis (1, 22, 25); L. versicolor (31).
Puccinia lactucicola Miura, see Puccinia minussensis.
Puccinia lateritia Berk. & Curt.: Hedyotis obliquinervis (16).
Puccinia lauricola Cumm.: Benzoin sp. (3); Lindera strychnifolia (3); undet. Lauraceae (3).
Puccinia leioderma Lindr.: Aegopodium alpestri (28).
Puccinia leucadis Syd.: Leucas ciliata (28, 31).
Puccinia leucophaea Syd. & Butl.: Colquhounia coccinea (31).
Puccinia leveillei Mont.: Geranium dahurica (33); G. eriostemon (33).
Puccinia levis (Sacc. & Bizz.) Magn.: Digitaria sanguinalis (22, 31).
Puccinia liberta Kern: Bulbostylis sp. (5); Eleocharis tuberosus (31).
Puccinia limosae Magn.: Lysimachia hui (19).
Puccinia lolii Niels., see Puccinia coronata.
Puccinia lomatogonii Petrak: Lomatogonium bicoronatum (28).
Puccinia longicornis Pat. & Har.: Bambusa spinosa (1); Phyllostachys sp. (1, 5, 35, 38, 44).
Puccinia longinqua Cumm.: Phragmites sp. (5).
Puccinia lycoctoni Fuck.: Aconitum fischeri (1).
Puccinia lysimachiae Karst.: Lysimachia clethroides (19).
Puccinia machili Cumm.: Machilus sp. (3).
Puccinia machilicola Cumm.: Machilus sp. (3).
Puccinia magnusiana Koern.: Phragmites communis (5, 28); P. longivalvis (14); P. vulgaris (1, 35, 38, 44); Ranunculus arcuans (35, 38); R. sieboldii (1).
Puccinia mammillata Schroet.: Polygonum divaricatum (1).
Puccinia mandshurica Miura: Carex siderosticta (1).
Puccinia maydis Bereng., see Puccinia sorghi.
Puccinia melanocephala Syd.: Phyllostachys puberula (5).
Puccinia melicae (Erikss.) Syd.: Melica nutans (1).
Puccinia menthae Pers.: Calamintha chinensis (1, 44); Lycopus europaeus (5); Mentha arvensis (1, 28, 31, 44); M. sacchalinensis (1, 14, 17); M. sp. (1, 35, 38); Origanum vulgare (5).
Puccinia millefolii Fuck.: Artemisia japonica (1, 25, 31); A. vulgaris (31); A. sp. (5, 35, 38).
Puccinia minussensis Thuem.: Lactuca brevirostris (1); L. denticulata (1, 44); L. indica (1, 14, 16, 22, 31); L. raddeana (1); L. sibirica (1); L. tatarica (28); L. thunbergiana (1); L. sp. (1, 5, 35, 38, 44).
Puccinia miscanthi Miura: Miscanthus sacchaliflorus (1); M. sacchariflorus (1); M. sinensis (1, 44).
Puccinia miscanthicola Tai & Cheo: Miscanthus sacchariflorus (33). This name (1937) antedates P. miscanthicola Tranz. (1939) and probably does not apply to the same rust. The latter develops aecia on Plantago and is the rust usually referred to as Puccinia eulaliae, a species which may not occur in China.
Puccinia mitriformis S. Ito: Bambusa tesselata (1).
Puccinia miyakei Syd.: Carex siderosticta (1).
Puccinia miyoshiana Diet.: Bupleurum falcatum (25); Spodiopogon cotulifer (1, 22, 44); S. sibiricus (1, 14, 25, 35, 38, 44).

Puccinia moliniae Tul.: Diplachne serotina (33).
Puccinia moliniicola Cumm.: Molinia sp. (5).
Puccinia morata Cumm.: Litsea sp. (3).
Puccinia morigera Cumm.: Eragrostis sp. (5).
Puccinia moriokaensis S. Ito: Phragmites vulgaris (1, 25); P. sp. (5).
Puccinia muehlenbeckiae (Cooke) Syd.: Muehlenbeckia platycladia (31).
Puccinia nakanishikii Diet.: Cymbopogon citratus (1, 44); C. nardus (1).
Puccinia nanbuana P. Henn.: Angelica dahurica (1); A. decursiva (1, 5, 44); A. sinuata (25); A. tshiliensis (25); A. sp. (33, 44); Peucedanum sp. (5, 35, 38).
Puccinia nasuensis Hirats. f.: undet. Orchidaceae (5).
Puccinia nepetae Togashi: Schizonepeta lavendulacea (1).
Puccinia nitidula Tranz.: Polygonum divaricatum (1, 15).
Puccinia nolitangeris Corda, see Puccinia argentata.
Puccinia oahuensis Ellis & Ev.: Digitaria sp. (5).
Puccinia obscura Schroet.: Luzula multiflora (31).
Puccinia obtecta Peck: Scirpus lacustris (1); S. triqueter (1).
Puccinia obtegens Tul.: Cephalonoplos segetum (14); C. setosum (14); Cirsium arvense (1, 5, 44); C. segetum (1, 22).
Puccinia oenanthes (Diet.) Miyake: Oenanthe stolonifera (1, 14, 22, 25, 31, 44); O. sp. (5, 35, 38).
Puccinia oenanthes-stoloniferae S. Ito, see Puccinia oenanthes.
Puccinia okatamaensis S. Ito: Phragmites vulgaris (1).
Puccinia orbicula Peck & Clint.: Prenanthes tatarinowii (33).
Puccinia orchidearum-phalaridis Kleb.: Gymnadenia canopsea (1).
Puccinia pachycephala Diet.: Veratrum sp. (31).
Puccinia pachypes Syd.: Spodiopogon sp. (35, 38). Specimens referred to this species by Teng are now in the Mycological Collections of the U. S. Department of Agriculture. The rust is not Puccinia pachypes but is generally similar to P. rufipes Diet.
Puccinia pangasinensis Syd.: Panicum sp. (5).
Puccinia paspalina Cumm.: Paspalum sp. (16).
Puccinia patriniae P. Henn.: Patrinia heterophylla (24); P. sp. (5, 31).
Puccinia phellopteri Syd.: Phellopterus littoralis (25).
Puccinia philippinensis Syd.: Cyperus sp. (1).
Puccinia phragmidioides Liou & Wang: Artemisia eriopoda (1). In a subsequent publication (1935) Liou and Wang consider this species to be the same as P. artemisiicola Syd., a species which has, however, been reported only from Europe.
Puccinia phragmitis (Schum.) Koern.: Phragmites communis (31); P. vulgaris (1, 22, 25, 35, 38, 44).
Puccinia phyllostachydis Kusano: Arundinaria sp. (1, 31); Phyllostachys sp. (1, 35, 38, 44).
Puccinia poae-pratensis Miura: Rhamnus davurica (1); Poa pratensis (1).
Puccinia poae-sudeticae (Westend.) Jorstad: Poa annua (22, 31); P. pratensis (15); P. sp. (5).
Puccinia poarum Niels.: Poa ocroleuca (1, 44).
Puccinia pogonatheri Petch: Pogonatherum sp. (16).
Puccinia polliniae Barcl.: Microstegium vimineum (31); Strobilanthes dryadum (31).
Puccinia polliniae-quadrinervis Diet.: Eulalia quadrinervis (31).
Puccinia polygoni-amphibii Pers.: Polygonum amphibium (1); P. convolvulus (14); P. cuspidatum (1, 22, 28, 31, 35, 38, 44); P. dumetorum (1, 14); P. longisetum (28); P. multiflorum (1, 22, 31, 35, 38, 44); P. perfoliatum (1); P. sagittatum (1); P. sieboldii (15); P. thunbergii (1); P. sp. (5).
Puccinia polygoni-lapathifoliae Liou & Wang: Polygonum lapathifolium (1, 15).
Puccinia polygoni-weyrichii Miyake: Polygonum lapathifolium (31); P. sp. (5).
Puccinia polygonicola Tai: Polygonum caespitosum (31); P. chinense (31); P. nepalense (22, 31).
Puccinia polysora Underw.: Setaria forbesciana (31). This record is undoubtedly erroneous since P. polysora is an American rust of Tripsacum and Zea. Puccinia chaetochloae Arth. is a similar rust of Setaria.
Puccinia polystegia Syd.: Eranthemum nervosum (1).
Puccinia porri (Sow.) Wint.: Allium fistulosum (31); A. tenuissimum (1); A. sp. (35, 38, 44).
Puccinia prenanthes-purpureae Lindr.: Prenanthes sp. (1).
Puccinia pruni-persicae Hori, see Leucotelium pruni-persicae.
Puccinia punctata Link: Galium dahuricum (15); G. verum (1, 14, 25); G. sp. (31).
Puccinia punctiformis Diet. & Holw.: Rumex acetosa (1, 44); R. crispus (22, 31); R. nepalensis (31); R. sp. (1, 14).

Puccinia purpurea Cooke: Erianthus fulvus (1). It is doubtful if P. purpurea occurs on Erianthus.

Puccinia pygmaea Erikss.: Berberis amurensis (herb. spec.); Calamagrostis arundinacea (5); C. epigejos (1, 15).

Puccinia rangiferina S. Ito: Agropyron ciliare (1); A. repens (1); Calamagrostis arundinacea (5); C. langsdorfii (1); Deyeuxia sylvatica (1); Melica sp. (1).

Puccinia romagnoliana Maire & Sacc.: Cyperus difformis (5, 31); C. rotundus (31).

Puccinia roscoeae Barcl.: Camptandra yunnanensis (31); Roscoea intermedia (31).

Puccinia rubigo-vera (DC.) Wint.: Aconitum volubile (25); Agropyron ciliare (1, 44); A. semicostatum (22, 31); Anemone sp. (5); Bromus sp. (44); Cimicifuga sp. (1); Clematis aquilegifolium (1); C. chinensis (25); C. heracleifolia (25, 28); C. paniculata (1, 44); C. potaninii (28); C. urcinata (25); C. sp. (1, 19, 35, 38); Dactylis glomerata (1); Delphinium sp. (44); Elymus sibiricus (1, 15); Potentilla sp. (44); Secale cereale (17, 22, 40); Thalictrum dipterocarpus (31); T. minus (1, 23, 25); T. simplex (1); Triticum aestivum (1, 22, 31, 44); T. vulgare (17, 38, 39, 44). The record on Potentilla is obviously erroneous.

Puccinia ruelliae Lagerh.: Ruellia repens (16).

Puccinia rufipes Diet.: Imperata cylindrica (1, 5, 15, 16, 22, 31, 44); Miscanthus sinensis (1).

Puccinia saniculae Grev.: Sanicula europaea (5).

Puccinia salviae Unger: Salvia sp. (1).

Puccinia saussureae-ussuriensis Liou & Wang: Saussurea ussuriensis (25); S. sp. (31).

Puccinia schirajewskii Tranz.: Serratula sp. (31).

Puccinia scimitriformis Cumm.: Persea sp. (3).

Puccinia scirpi DC.: Scirpus lacustris (1); S. maritimus (25).

Puccinia scirpi-ternatani Hirats. f.: Scirpus sp. (5).

Puccinia scleriae-dregeanae Doidge: Scleria sp. (5).

Puccinia scorzonerae Jacky: Scorzonera austriaca (1).

Puccinia seposita Cumm.: Benzoin sp. (3).

Puccinia septentrionalis Juel: Thalictrum simplex (1).

Puccinia sessilis Schneid.: Phalaris arundinacea (15).

Puccinia shiraiana Syd.: Dicliptera sp. (23); Justicia procumbens (1, 19, 23, 31, 35, 39, 44); J. xerobatica (31).

Puccinia silenes Schroet., see Puccinia behenis.

Puccinia sileris Voss: Siler divaricatum (1, 24).

Puccinia silvatica Schroet.: Carex caespitosa (1); C. neurocarpi (1); C. sp. (1, 35, 38); Lactuca chinensis (1).

Puccinia simillima Arth., see Puccinia magnusiana.

Puccinia simplex (Koern.) Erikss. & Henn., see Puccinia hordei.

Puccinia sinica Syd.: Muehlenbergia hugelii (1, 31, 44).

Puccinia sinicensis Cumm.: Undet. Orchidaceae (5).

Puccinia smilacinae Syd.: Polygonatum sp. (5).

Puccinia smilacis Schw.: Smilax sp. (35, 39). No oriental Smilax rust seen by the authors can be identified with Puccinia smilacis, which develops aecia on Apocynum.

Puccinia smilacis-chinae P. Henn.: Smilax china (1, 38); S. sp.: (8, 35, 38).

Puccinia smilacis-sempervirentis Wang: Smilax sempervirens (42).

Puccinia sonchi Rob.: Sonchus arvensis (1, 23); S. brachyotus (14).

Puccinia sorghi Schw.: Oxalis corniculata (22); Zea mays (5, 17, 22, 31, 35).

Puccinia stellariae Liou & Wang not Duby, see Puccinia stellariicola.

Puccinia stellariicola Cumm.: Stellaria sp. (1, 5).

Puccinia stipae Auth. not Arth., see Puccinia stipina.

Puccinia stipae-sibiricae S. Ito: Sedum aizoon (1); S. kamtschaticum (1); Stipa extremiorientalis (15).

Puccinia stipina Tranz.: Stipa splendens (1). Records credited to Puccinia stipae probably should be referred to P. stipina.

Puccinia subhyalina Tranz.: Carex sp. (5).

Puccinia swertiae Wint.: Swertia sp. (31).

Puccinia taliensis Tai: Polygonum paleaceum (31); P. viviparum (31).

Puccinia tanaceti DC.: Artemisia vulgaris (1). This record should probably be referred to Puccinia absinthii.

Puccinia tangkuensis Liou & Wang: Aeluropus littoralis (25).

Puccinia taraxaci Plowr., see Puccinia hieracii.

Puccinia tatarica Tranz., see Puncinia minussensis.

Puccinia tenuis Burr.: Eupatorium sp. (5).
Puccinia thalictri Chev., see Tranzschelia thalictri.
Puccinia themedae Hirats. f.: Themeda triandra (31).
Puccinia thwaitesii Berk.: Justicia gendarussa (16).
Puccinia tinctoriae Magnus not Speg., see Puccinia tinctoriicola.
Puccinia tinctoriicola Magn.: Serratula centaureoides (1).
Puccinia tokyensis Syd.: Cryptotaenia canadensis (1, 24, 44); C. japonica (23, 35, 38); C. sp. (1, 5).
Puccinia tossoensis Tokunaga & Kawai: Synurus hondae (24).
Puccinia tranzschelii Diet.: Cacalia hastata (15).
Puccinia triseti Erikss.: Trisetum flavescens (1); T. micranthum (22).
Puccinia triticina Erikss., see Puccinia rubigo-vera.
Puccinia urticae Barcl., see Puccinia fusispora.
Puccinia veratri Duby: Veratrum dolichopetalum (14).
Puccinia veratricola Tai: Veratrum taliensis (31).
Puccinia violae DC.: Viola acuminata (24); V. betonicifolia (22, 31); V. canescens (1, 44); V. gryptoceras (22); V. mandshurica (14); V. patrinii (22, 31); V. prionantha (1).
Puccinia waldsteiniae Curtis: Waldsteinia sibirica (1, 18).
Puccinia wattiana Barcl.: Clematis peterae (31); C. sp. (5).
Puccinia yokokurae P. Henn: Carex heterolepis (31).
Puccinia yunnanensis Tai: Polygonum cymosum (31).
Puccinia zoysiae Diet.: Aeluropus littoralis (1); Paederia foetida (1); P. scandens (1, 24, 25, 35, 38); P. sp. (1, 16, 31); Zoysia japonica (25); Z. matrella (1).
Puccinia sp.: Carex fluviatilis (22); Oplismenus undulatifolius (22); Phaenosperma globosa (22).
PUCCINIASTRUM agrimoniae (Diet.) Tranz.: Agrimonia eupatoria (1, 25, 44); A. pilosa (1, 10, 14); A. zeylanica (31); A. sp. (4).
Pucciniastrum castaneae Diet.: Castanea mollissima (22, 31); C. sp. (4).
Pucciniastrum circaeae (Thuem.) Speg.: Circaea caulescens (14).
Pucciniastrum coriariae Diet.: Coriaria sinica (4, 22, 31).
Pucciniastrum coryli Kom.: Corylus heterophylla (1, 10, 14, 18, 20).
Pucciniastrum epilobii Otth: Chamaenerion angustifolium (14).
Pucciniastrum hydrangeae-petiolaridis Hirats. f.: Hydrangea sp. (4).
Pucciniastrum potentillae Kom.: Fragaria? sp. (4); Potentilla fragarioides (1, 10, 14, 18, 20); P. multifida (15).
Pucciniastrum tiliae Miyabe: Tilia amurensis (1, 10, 18); T. manshurica (10); T. tuan (4).
PUCCINIOSTELE clarkiana (Barcl.) Diet.: Astilbe thunbergii (24).
Pucciniostele hashiokai (Hirats. f.) Cumm.: Ampelopsis sp. (4).
Pucciniostele mandshurica Diet.: Astilbe chinensis (1, 4, 6, 8, 18, 20, 44); in part as P. clarkiana.
PUERARIA (Leguminosae) thunbergiana (Sieb. & Zucc.) Benth.: Phakopsora pachyrhizae.
PULSATILLA (Ranunculaceae) cernua Spreng.: Tranzschelia suffusca.
Pulsatilla chinensis (Bunge) Regel: Coleosporium pulsatillae; Tranzschelia fusca; Tranzschelia pruni-spinosae; Tranzschelia suffusca.
Pulsatilla dahurica Spreng.: Coleosporium pulsatillae; Tranzschelia fusca.
Pulsatilla koreana Nakai: Tranzschelia fusca.
PYROLA (Pyrolaceae) rotundifolia L.: Chrysomyxa pyrolae.
PYRUS (Rosaceae) betulifolia Bunge, P. calleryana Dcne., P. communis L., P. lindleyi Rehd.: Gymnosporangium haraeanum.
Pyrus malus L., see Malus pumila.
Pyrus montana Nakai, see Pyrus pyrifolia.
Pyrus pyrifolia (Burm.) Nakai: Gymnosporangium haraeanum; Gymnosporangium japonicum.
Pyrus serotina Rehd., see Pyrus pyrifolia.
Pyrus ussuriensis Maxim., P. sp.: Gymnosporangium haraeanum.
QUERCUS (Fagaceae) acutissima Carruthers, Q. fabri Hance, Q. glandulifera Blume, Q. glauca Thunb., Q. serrata Thunb., Q. variabilis Blume: Cronartium quercuum.
RANDIA (Rubiaceae) sinensis Roem. & Schult.: Endophyllum griffithiae.
RANUNCULUS (Ranunculaceae) arcuans Chien: Puccinia magnusiana.
Ranunculus catoniensis DC., R. japonicus Thunb.: Aecidium ranunculacearum.
Ranunculus sieboldii Miq.: Puccinia magnusiana.
RAPHIOLEPIS (Rosaceae) indica Lindl.: Aecidium raphiolepidis.
RAVENELIA atrides Syd.: Grewia parviflora (4).
Ravenelia indigoferae Tranz.: Indigofera sp. (4).

Ravenelia indigoferae-scabridae Tai: Indigofera scabrida (31).
Ravenelia japonica Diet. & Syd.: Albizzia julibrissin (22); A. kalkora (1, 25, 31, 33, 35, 38, 44); A. sp. (14).
Ravenelia laevis Diet. & Syd.: Indigofera cinerascens (31).
Ravenelia macrocapitula Tai: Indigofera dielsiana (31); I. hancockii (31).
Ravenelia ornata Syd.: Abrus mollis (16).
Ravenelia sessilis Berk.: Albizzia sp. (35, 38); undet. Leguminosae (1).
RHAMNELLA (Rhamnaceae) martini, R. obovalis Schneid., R. sp.: Puccinia coronata.
RHAMNUS (Rhamnaceae) crenata Sieb. & Zucc.: Puccinia coronata.
Rhamnus davurica Pall.: Puccinia poae-pratentis (1).
Rhamnus globosa Bunge, R. japonica Maxim., R. kulingensis Schneid., R. leptophylla Schneid., R. parvifolia Bunge, R. utilis Dcne.: Puccinia coronata.
Rhamnus sp.: Aecidium alaterni; Aecidium rhamni-japonici; Puccinia coronata.
RHODODENDRON (Ericaceae) calvescentum Balf. f. & Forerst: Aecidium sino-rhododendri.
Rhododendron dauricum L., R. decorum Franch., R. faberi Hemsl., R. micranthum Turcz.: Chrysomyxa rhododendri.
Rhododendron trichocladum Franch.: Chrysomyxa dietelii.
Rhododendron sp.: Chrysomyxa expansa.
RHODOTYPUS (Rosaceae) scandens (Thunb.) Mak.: Pileolaria dieteliana (1).
RHUS (Anacardiaceae) chinensis Mill.: Pileolaria klugkistiana.
Rhus delavayi Franch.: Pileolaria shiraiana.
Rhus javanicus Thunb., see R. chinensis.
Rhus potaninii Maxim., R. punjabensis Stewart; Pileolaria klugkistiana.
Rhus semialata Merr., see R. chinensis.
Rhus sylvestris Sieb. & Zucc., R. verniciflua Stokes: Pileolaria shiraiana.
Rhus sp.: Pileolaria klugkistiana; Pileolaria shiraiana.
RIBES (Saxifragaceae) coeleste Jancz.: Cronartium ribicola.
Ribes diacanthum Pall.: Melampsora ribesii-purpureae; Puccinia caricis.
Ribes fasciculatum Sieb. & Zucc.: Puccinia caricis.
Ribes mandschuricum (Maxim.) Kom.: Cronartium ribicola; Puccinia caricis (1).
RICINUS (Euphorbiaceae) communis L.: Melampsora ricini.
ROEGNERIA (Gramineae), see Agropyron.
ROESTELIA koreaensis P. Henn., see Gymnosporangium haraeanum.
Roestelia lacerata Merr.: Cotoneaster sp. (1).
ROSA (Rosaceae) acicularis Lindl.: Phragmidium kamtschatkae.
Rosa banksiae Ait.: Caeoma warburgianum.
Rosa chinensis Jacq.: Phragmidium rosae-multiflorae.
Rosa cymosa Tratt.: Gerwasia rosae; Phragmidium sp.
Rosa davidii Crep.: Phragmidium disciflorum.
Rosa davurica Pall.: Phragmidium kamtschatkae; Phragmidium montivagum; Phragmidium rosae-davuricae.
Rosa glomerata Rehd. & Wils.: Phragmidium fusiforme; Phragmidium handelii.
Rosa longicuspis Bertol.: Caeoma warburgianum.
Rosa lucens Rolfe, see Rosa longicuspis.
Rosa microcarpa Lindl., see Rosa cymosa.
Rosa multiflora Thunb.: Phragmidium disciflorum; Phragmidium rosae-multiflorae.
Rosa odorata Sweet: Phragmidium disciflorum.
Rosa omeiensis Rolfe: Phragmidium rosae-rugosae.
Rosa roxburghii Tratt.: Gerwasia rosae.
Rosa rugosa Thunb.: Phragmidium disciflorum; Phragmidium rosae-rugosae; Phragmidium yezoense.
Rosa sempervirens L.: Phragmidium disciflorum.
Rosa sp.: Caeoma warburgiana; Phragmidium disciflorum; Phragmidium kamtschatkae; Phragmidium rosae-davuricae; Phragmidium rosae-multiflorae; Phragmidium receptaculorum; Phragmidium tuberculatum.
ROSCOEA (Zingiberaceae) intermedia: Puccinia roscoeae.
ROSTRUPIA dioscoreae (Kom.) Syd., see Puccinia dioscoreae.
Rostrupia elymi (Westend.) Lagerh., see Puccinia rubigo-vera.
ROTTBOELLIA (Gramineae) compressa L., R. sp.: Puccinia cacao.
RUBIA (Rubiaceae) cordifolia L.: Aecidium rubiae; Coleosporium rubiicola; Puccinia collettiana; Thekopsora rubiae.

Rubia sylvatica Nakai: Thekopsora rubiae.
RUBUS (Rosaceae) amplifolius Levl. & Van, R. cochinchinensis Tratt.: Gerwasia chinensis.
Rubus crataegifolius Bunge: Phragmidium griseum; Phragmidium sinicum.
Rubus ellipticus Smith: Hamaspora benguetensis.
Rubus hupehensis Oliv.: Gerwasia chinensis; Gerwasia rubi.
Rubus idaeus L.: Phragmidium shensianum; Phragmidium rubi-parvifoliae.
Rubus lambertianus Ser.: Hamaspora longissima.
Rubus moluccanus L., see Rubus reflexus.
Rubus morifolius Sieb.: Phragmidium griseum.
Rubus parkeri Hance: Hamaspora sinica.
Rubus parvifolius L.: Phragmidium pauciloculare; Phragmidium rubi-parvifolii.
Rubus phoenicolasius Maxim., R. pinnatisepalus Hemsl.: Hamaspora sinica.
Rubus pungens Cambess: Phragmidium sikangensis.
Rubus reflexus (DC.) Ker: Gerwasia chinensis.
Rubus rosaefolius Sm.: Phragmidium pauciloculare.
Rubus saxatilis L.: Gymnoconia interstitialis.
Rubus setchuensis Bur. & Fr.: Hamaspora acutissima; Gerwasia chinensis; Gerwasia rubi.
Rubus subornatus Focke: Phragmidium pauciloculare.
Rubus swinhoei Bean, see Rubus hupehensis.
Rubus thunbergii Sieb. & Zucc.: Phragmidium rubi-thunbergii.
Rubus trianthus Focke: Hamaspora sinica.
Rubus triphyllus Thunb.: Phragmidium pauciloculare.
Rubus sp.: Caeoma cheoanum; Gerwasia chinensis; Hamaspora acutissima; Hamaspora benguetensis; Hamaspora hashiokai; Hamaspora longissima; Hamaspora sinica; Phragmidium griseum; Phragmidium nanbuanum; Phragmidium okianum; Phragmidium pauciloculare; Phragmidium rubi-parvifolii; Phragmidium rubi-thunbergii; Phragmidium violaceum.
RUELLIA (Acanthaceae) repens L.: Puccinia ruelliae.
RUMEX (Polygonaceae) acetosa L., R. crispus L.: Puccinia punctiformis.
Rumex dentatus L.: Puccinia acetosae.
Rumex nepalensis Meisnn.: Puccinia punctiformis.
Rumex sp.: Puccinia acetosae; Puccinia punctiformis; Uromyces polygoni; Uromyces rumicis.
SACCHARUM (Gramineae) arundinaceum Retz., S. nargena (Nees) Hack., S. spontaneum L., S. sp.: Puccinia kuehnii.
Saccharum sp.: Puccinia eulaliae; Puccinia kuehnii.
SAGERETIA (Rhamnaceae) pycnophylla Schneid., S. sp.: Aecidium sageretiae.
SALIX (Salicaceae) babylonica L.: Melampsora coleosporioides.
Salix cavaleriei Lév.: Melampsora salicis-cavaleriei.
Salix delavayana Hand.-Mazz.: Melampsora larici-epitea.
Salix heteromera Hand.-Mazz.: Melampsora coleosporioides.
Salix longifolia Muhl.: Melampsora larici-epitea; Melampsora yezoensis.
Salix matsudana Koidz., S. mesneyi Hance: Melampsora coleosporioides.
Salix psilostigma Anderss.: Melampsora larici-epitea.
Salix purpurea L.: Melampsora ribesii-purpureae.
Salix viminalis L.: Melampsora larici-epitea.
Salix wilsonii Seem.: Melampsora farinosa; Melampsora ribesii-purpureae.
Salix sp.: Melampsora larici-epitea; Melampsora ribesii-purpureae; Melampsora salicis-albae.
SALVIA (Labiatae) sp.: Puccinia delavayana; Puccinia salviae.
SAMBUCUS (Caprifoliaceae) racemosa L.: Puccinia bolleyana.
Sambucus sieboldiana Graebn.: Aecidium sp.; Puccinia bolleyana.
SANGUISORBA (Rosaceae), see also Poterium.
Sanguisorba officinalis L.: Xenodochus carbonarius.
SANICULA (Umbelliferae) europaea L.: Puccinia saniculae.
SASA (Gramineae), see Bambusa.
SATUREIA (Labiatae), see Calamintha.
SAURURUS (Saururaceae) chinensis Hort.: Uromyces saururi.
SAUSSUREA (Compositae) cordifolia Hemsl., S. glomerata Poir., S. japonica DC., S. manshurica Kom., S. maximowiczii Herd., S. odontolepis Sch.-Bip., S. peduncularis Franch.: Coleosporium saussureae.
Saussurea pectinata Bunge: Phakopsora compositarum.
Saussurea pulchella DC., S. serrata DC., S. triangulata Trautv. & Mey.: Coleosporium saussureae.

Saussurea ussuriensis Maxim.: Coleosporium saussureae; Puccinia saussureae-ussuriensis.
Saussurea sp.: Coleosporium saussureae; Puccinia kwangsiana; Puccinia saussureae-ussuriensis.
SAXIFRAGACEAE undet.: Coleosporium fauriae.
SCEPTROENIDE (Urticaceae) sp.: Puccinia caricina.
SCHIZANDRA (Magnoliaceae) sphenanthera Rehd. & Wils.: Aecidium sp.
SCHIZONEPETA (Labiatae) lavandulacea (L.f.) Briq.: Puccinia nepetae.
SCHROETERIASTER cingens Syd., see Phakopsora cingens.
SCILLA (Liliaceae) sp.: Uromyces erythronii.
SCIRPUS (Cyperaceae) lacustris L.: Puccinia obtecta; Puccinia scirpi.
Scirpus maritimus L.: Puccinia scirpi.
Scirpus radicans Schkuhr: Uromyces haraeanus.
Scirpus triqueter L.: Puccinia obtecta; Uromyces junci.
Scripus sp.: Puccinia scirpi-ternatani; Uredo sp.
SCLERIA (Cyperaceae) sp.: Puccinia scleriae-dregeanae.
SCOLOPIA (Solanaceae) sp.: Uredo scolopiae.
SCORZONERA (Compositae) austriaca L.: Puccinia scorzonerae.
SCUTELLARIA (Labiatae) sp.: Aecidium scutellariae-indicae.
SECALE (Gramineae) cereale L.: Puccinia graminis; Puccinia rubigo-vera.
SECURINEGA (Euphorbiaceae) fluggeoides Muell.-Arg., S. suffruticosa (Pall) Rehd.: Nothoravenelia japonica.
SEDUM (Crassulaceae) aizoon L.: Aecidium shansiensis; Puccinia stipae-sibiricae.
Sedum kamtschaticum Fisch. & Mey.: Puccinia stipae-sibiricae.
Sedum spinosum (L.) Willd., S. telephium L.: Puccinia australis.
SEMIAQUILEGIA (Ranunculaceae) adoxoides (DC.) Maxim.: Aecidium isopyri; Aecidium semiaquilegiae.
SENECIO (Compositae) argunensis Turcz., S. canabifolius Less., S. densiflorus Wall., S. dianthus Franch.: Coleosporium senecionis.
SERRATULA (Compositae) atriplicifolia, see Synurus hondae.
Serratula centaureoides L.: Puccinia tinctoriicola.
Serratula sp.: Puccinia schirajewskii.
SESELI (Umbelliferae) condensatum Reichb.: Puccinia bullata.
SETARIA (Gramineae) glauca Beauv.: Uromyces setariae-italicae.
Setaria forbesciana Hook. f.: Puccinia polysora.
Setaria italica Beauv., S. lutescens (Weigel) F. T. Hubb.: Uromyces setariae-italicae.
Setaria plicata (Lam.) T. Cooke: Uredo sp.
Setaria viridis Beauv.: Uromyces setariae-italicae.
Setaria sp.: Uromyces leptodermus.
SHUTERIA (Leguminosae) sp.: Phakopsora pachyrhizae.
SIDA (Malvaceae) glutinosa Carr., S. veronicaefolia Sam., S. sp.: Puccinia heterospora.
SIEGESBECKIA (Compositae) orientalis L.: Coleosporium sp.
SILENE (Caryophyllaceae) fortunei Vis.: Uromyces caryophyllinus; Uromyces inaequialtus.
Silene sp.: Puccinia behenis.
SILER (Umbelliferae) divaricatum B. & H.: Puccinia sileris.
SMILAX (Liliaceae) china L.: Aecidium smilacis; Puccinia ferruginea; Puccinia smilacis; Puccinia smilacis-chinae.
Smilax davidiana A. DC.: Puccinia ferruginea.
Smilax gaudichaudiana Kunth: Puccinia citrina; Puccinia ferruginea.
Smilax glauca-china Warb., S. longipes Warb.: Puccinia ferruginea.
Smilax menispermoides A. DC.: Puccinia henryana.
Smilax sempervirens Wang: Puccinia smilacis-sempervirentis.
Smilax sp.: Aecidium smilacis; Puccinia citrina; Puccinia ferruginea; Puccinia henryana; Puccinia smilacis; Puccinia smilacis-chinae.
SOLIDAGO (Compositae) virgaurea L.: Puccinia lactucae; Uromyces komarovii; Uromyces solidaginis.
SONCHUS (Compositae) arvensis L., S. brachyotus DC.: Puccinia sonchi. See also Coleosporium sonchi-arvensis.
SOPHORA (Leguminosae) flavescens Ait.: Uromyces sophorae-flavescentis.
Sophora japonica L.: Uromyces truncicola.
Sophora viciifolia Hance: Aecidium anningense; Uromyces sophorae-viciifoliae.
Sophora sp.: Uromyces sophorae-japonicae.

SORBUS (Rosaceae) alnifolia (Sieb. & Zucc.) K. Koch: Gymnosporangium nipponicum.
Sorbus valbrayi Lév.: Gymnosporangium juniperinum.
SORGHUM (Gramineae) vulgare Pers.: Puccinia eulaliae.
SPATHOGLOTTIS (Orchidaceae) pubescens Lindl.: Coleosporium arundinae.
SPHAEROPHRAGMIUM acaciae (Cooke) Mayn.: Albizzia lebbek (1, 16, 29, 35, 38).
SPODIOPOGON (Gramineae) cotulifer (Thunb.) Hack., S. sibiricus, Trin.: Puccinia miyoshiana.
Spodiopogon sp.: Puccinia miyoshiana; Puccinia pachypes.
SPONDIAS (Anacardiaceae) axillaris Roxb.: Nyssopsora cedrelae.
SPOROBOLUS (Gramineae) indicus (L.) R. Br.: Puccinia arundinellae-setosae; Uromyces tenuicutis.
STAPHYLEA (Staphyleaceae) bumalda DC.: Aecidium staphyleae.
STATICE (Plumbaginaceae) aurea L., S. bicolor Bunge, S. japonica Sieb. & Zucc.: Uromyces limonii.
Statice sinensis Girard: Uromyces statice-sinensis.
STELLARIA (Caryophyllaceae) chinensis Regel, S. paniculata Edgew.: Puccinia arenariae.
Stellaria saxatilis Buch.-Ham.: Puccinia arenariae; Uromyces inaequialtus.
Stellaria sp.: Puccinia stellariicola; Uromyces leptaleus.
STELLERA (Thymelaeaceae) chamaejasme L.: Melampsora stellerae.
STEREOSTRATUM corticioides (Berk. & Br.) Magn.: Arundinaria sp. (19, 35, 38); Phyllostachys puberula (1); P. sp. (1, 35, 38).
STIPA (Gramineae) extremiorientalis Hara: Puccinia stipae-sibiricae.
Stipa splendens Trin.: Puccinia stipina.
STROBILANTHES (Acanthaceae) dryadum Benoist: Puccinia polliniae.
SWERTIA (Gentianaceae) sp.: Puccinia swertiae.
SYNURUS (Compositae) hondae Kitagawa: Puccinia tossoensis.
TARAXACUM (Compositae) heterolepis Nakai, T. mongolicum Hand.-Mazz., T. officinale Weber, T. sinensis Dahlst.: Puccinia hieracii.
THALICTRUM (Ranunculaceae) dipterocarpum Franch.: Puccinia rubigo-vera.
Thalictrum minus L.: Puccinia rubigo-vera; Tranzschelia thalictri.
Thalictrum przewalskii Maxim.: Aecidium urceolatum.
Thalictrum simplex L.: Puccinia rubigo-vera; Puccinia septentrionalis.
THEKOPSORA areolata (Fr.) Magn.: Prunus sp. (1).
Thekopsora brachybotrydis Tranz.: Brachybotrys paridifolius (1, 10, 41); Trigonotis radicans (14).
Thekopsora guttata (Schroet.) Syd.: Galium dahuricum (15); G. verum (14).
Thekopsora rubiae Kom.: Rubia cordifolia (1, 14, 18, 20, 23, 33); R. sylvatica (14).
THELYPTERIS (Polypodiaceae) palustris Schott: Uredinopsis hirosakiensis.
THEMEDA (Gramineae) triandra Forsk.: Puccinia themedae.
TILIA (Tiliaceae) amurensis Rupr., T. manshurica Rupr. & Maxim., T. tuan Szysz.: Pucciniastrum tiliae.
TOONA (Meliaceae) sp.: Nyssopsora cedrelae.
TRANZSCHELIA fusca (Pers.) Diet.: Pulsatilla chinensis (1, 33, 35, 38); P. dahurica (1); P. koreana (14).
Tranzschelia pruni-spinosae (Pers.) Diet.: Prunus glandulosa (1, 25); P. mandshurica (1, 17); P. persica (1, 4, 16, 22, 31, 35, 44); P. salicina (22); Pulsatilla chinensis (1, 35, 38).
Tranzschelia pulsatillae (Rostr.) Diet., see Tranzschelia suffusca.
Tranzschelia suffusca (Holw.) Arth.: Pulsatilla cernua (22, 31); P. chinensis (28).
Tranzschelia thalictri (Chev.) Diet.: Thalictrum minus (1, 33).
TRIFOLIUM (Leguminosae) lupinaster L.: Uromyces minor.
Trifolium repens L.: Uromyces striatus.
TRIGONOTIS (Boraginaceae) peduncularis Benth.: Aecidium eritrichii.
Trigonotis radicans Steven.: Thekopsora brachybotrydis.
TRIPHRAGMIUM anomalum Tranz.: Filipendula palmata (14).
Triphragmium chinense Tai & Cheo: Koelreuteria paniculata (33).
Triphragmium clavellosum Berk. f. asiatica Kom., see Nyssopsora thwaitesii.
Triphragmium koelreuteriae Syd.: Koelreuteria bipinnata (1, 33, 44); K. paniculata (44); K. sp. (33, 35, 38).
Triphragmium thwaitesii Berk. & Br., see Nyssopsora thwaitesii.
Triphragmium ulmariae (Schum.) Link: Filipendula palmata (1).
TRISETUM (Gramineae) flavescens (L.) Beauv., T. micranthum (Hack.) Keng: Puccinia triseti.

TRITICUM (Gramineae) aestivum L., T. vulgare Vill.: Puccinia glumarum (1, 17,22, 31, 38, 44); Puccinia graminis (1, 14, 17, 22, 31, 38, 44); Puccinia rubigo-vera (1, 17, 22, 33, 38, 39, 40).
TSUGA (Pinaceae) yunnanensis (Franch.) Mast.: Chrysomyxa tsugae-yunnanensis.
TULIPA (Liliaceae) edulus (Miq.) Bak.: Uromyces erythronii.
UREDINOPSIS adianti Kom.: Adiantum pedatum (1, 10, 14, 18, 20).
Uredinopsis filicina (Niessl) Magn.: Phegopteris polypodioides (14).
Uredinopsis hirosakiensis Kamei & Hirats. f.: Thelypteris palustris (15).
Uredinopsis kameiana Faull: Pteridium aquilinum (15).
Uredinopsis macrosperma Arth., see Uredinopsis pteridis.
Uredinopsis pteridis Diet. & Holw.: Pteridium aquilinum (1, 8, 10).
UREDO alpestris Schroet.: Viola sp. (5).
Uredo artemisiae-japonicae Diet., see Phakopsora artemisiae.
Uredo arthraxonis-ciliaris P. Henn.: Arthraxon hispidus (31); A. sp. (5).
Uredo arundinis-donacis Tai: Arundo donax (31).
Uredo asteromoeae P. Henn., see Coleosporium asterum.
Uredo autumnalis Diet., see Phakopsora artemisiae.
Uredo callicarpae Petch: Callicarpa cana (35, 38).
Uredo cantonensis Yates, see Puccinia arisanensis.
Uredo chinensis Diet., see Gerwasia chinensis.
Uredo clerodendricola P. Henn., see Puccinia erebia.
Uredo colebrookiae Barcl.: Colebrookia oppositifolia (31).
Uredo cynodontis-dactylis Tai: Cynodon dactylon (31).
Uredo cyperi-tagetiformis P. Henn., see Puccinia cyperi-tagetiformis.
Uredo daphnicola Diet.: Daphne odora (1).
Uredo davaoensis Syd.: Cyanotis sp. (1).
Uredo dendrocalami Petch: Dendrocalamus latiflorus (1).
Uredo deutziae Barcl.: Deutzia discolor (31).
Uredo dianellae Diet.: Dianella ensifolia (1); D. sp. (35, 39).
Uredo ehretiae Barcl.: Ehretia macrophyllum (22).
Uredo ignava Arth.: Bambusa spinosa (35, 38); Dendrocalamus (35, 38).
Uredo iyoensis Hirats. f.: Viola sp. (5).
Uredo kyllingae P. Henn.: Kyllinga brevifolia (1, 5, 31, 35, 38).
Uredo lini Schum., see Melampsora lini.
Uredo nervicola Tranz.: Potentilla fragarioides (1, 41).
Uredo paederiae Syd.: Paederia foetida (35, 38).
Uredo panacis Syd.: Panax pseudo-ginsing (31).
Uredo paspalina Syd., see Puccinia paspalina.
Uredo philippinensis Syd., see Puccinia philippinensis.
Uredo rottboelliae Diet., see Puccinia cacao.
Uredo scolopiae Syd.: Scolopia sp. (16).
Uredo sinensis (Syd.) Trott.: Cudrania sp. (1).
Uredo sojae P. Henn., see Phakopsora pachyrhizae.
Uredo themedae Diet., see Puccinia themedae.
Uredo tholopsora Cumm.: Populus nigra (5); P. tomentosa (5).
Uredo verecunda Syd.: Achyranthes aspera (31).
Uredo vignae Bres., see Phakopsora pachyrhizae.
Uredo zehneriae Thuem,, see Puccinia arisanensis .
Uredo sp.: Origanum sp. (5); Oryzopsis obtusa (22); Scirpus sp. (5); Setaria plicata (22).
UROMYCES aconiti Fuck.: Aconitum delavayi (1).
Uromyces aconiti-lycoctoni Wint., see Uromyces aconiti.
Uromyces allii-victorialis Liou & Wang: Allium victorialis (1, 33).
Uromyces alopecuri Seym.: Alopecurus aequalis (1, 35, 38, 44); A. amurensis (14); A. geniculatus (1, 44); A. japonicus (22); A. pratensis (31); A. sp. (5).
Uromyces amurensis Kom.: Maakia amurensis (1, 18); Milletia reticulata (5).
Uromyces appendiculatus Link, see Uromyces phaseoli.
Uromyces baeumlerianus Bubak: Mellilotus indicus (1, 22, 44).
Uromyces bidenticola (P. Henn.) Arth.: Bidens pilosa (31).
Uromyces callicarpae Fujikuro: Callicarpa sp. (16).
Uromyces capitatus Syd.: Desmodium yunnanense (1).
Uromyces caryophyllinus Wint.: Dianthus caryophyllus (22); D. chinensis (1, 35, 38); D. longicalyx (1, 44); Gypsophila oldhamiana (1); Silene fortunei (1).

Uromyces chinensis Diet., see Gerwasia chinensis.
Uromyces clignii Pat. & Har.: Andropogon ischaemum (1).
Uromyces commelinae (Speg.) Cooke: Aneilema sp. (35, 38); Commelina communis (1, 44); C. nudiflora (44); C. sp. (5, 35, 38); Pollia sp. (5, 35, 38).
Uromyces coronatus Miyabe & Nishida: Oryza sativa (25); Zizania aquatica (25); Z. latifolia (1, 31, 35, 38, 44); Z. sp. (5).
Uromyces crassivertex Diet.: Lychnis sp. (5).
Uromyces decoratus Syd.: Crotalaria lonchophylla (31).
Uromyces dolicholi Arth.: Cajanus cajan (35, 38).
Uromyces eriochloae Syd. & Butl.: Eriochloa villosa (14, 34).
Uromyces ervi (Wallr.) Westend.: Vicia kulingana (13); V. sativa (13); V. tetrasperma (31).
Uromyces erythronii (DC.) Pass.: Scilla sp. (1); Tulipa edulis (1, 35, 38, 44).
Uromyces fabae (Pers.) de Bary: Vicia cracca (14, 33); V. faba (1, 14, 17, 22, 31, 33, 35, 38, 39, 44); V. kulingana (1, 44); V. sativa (1, 31, 44); V. tetrasperma (1); V. unijuga (5, 33).
Uromyces genistae-tinctoriae (Pers.) Wint.: Caragana ambigua (34); C. chamlagu (1, 14, 34, 44); C. frutex (34); C. microphylla (1, 34); C. rossa (1); C. sophoraefolia (34); Gueldenstaedtia multiflora (1). The last entry perhaps should refer to Uromyces kondoi.
Uromyces geranii (DC.) Otth: Geranium eriostemon (1, 33); G. nepalensis (1, 31); G. orientale-tibeticum (1); G. sibiricum (14, 33); G. sp. (1, 5, 35, 38).
Uromyces glycyrrhizae (Rabenh.) Magn.: Glycyrrhiza echinata (1); G. glabra (17); G. glandulifera (23); G. squamulosa (28); G. uralensis (28).
Uromyces gueldenstaedtiae Liou & Wang, see Uromyces kondoi.
Uromyces halstedii De Toni: Leersia sp. (35, 38).
Uromyces haraeanus Syd.: Scirpus radicans (15).
Uromyces hedysari-obscuri (DC.) Carr. & Picc.: Hedysarum obscurum (1).
Uromyces heimerlianus Magn.: Vicia unijuga (1, 25, 28).
Uromyces hyperici Curt.: Hypericum japonicum (16); H. sp. (5).
Uromyces inaequialtus Lasch: Silene fortunei (33, 35, 38); Stellaria saxatilis (31).
Uromyces inayati Syd.: Apluda mutica (35, 38).
Uromyces itoanus Hirats. f.: Lespedeza striata (1); L. stipulacea (14).
Uromyces junci (Desm.) Wint.: Scirpus triqueter (1). This record obviously is erroneous, either as to rust or host.
Uromyces komarovii Bubak: Solidago virgaurea (2).
Uromyces kondoi Miura: Gueldenstaedtia delavayi (31); G. multiflora (1, 12, 23); G. stenophylla (12, 23); G. sp. (25, 32).
Uromyces kwangsianus Cumm.: Fimbristylis sp. (5).
Uromyces lapponicus Lagerh.: Oxytropis sp. (1).
Uromyces leptaleus Syd.: Stellaria sp. (5).
Uromyces leptodermus Syd.: Setaria sp. (5).
Uromyces lespedezae-bicoloris Tai & Cheo: Lespedeza bicolor (33).
Uromyces lespedezae-macrocarpae Liou & Wang: Campylotropis chinensis (1).
Uromyces lespedezae-procumbentis (Schw.) Curt.: Lespedeza bicolor (1, 14, 28, 44); L. chinensis (1); L. cuneata (1); L. daurica (1, 14, 25); L. floribunda (1); L. formosa (28); L. hedysaroides (14); L. juncea (1, 25, 31, 44); L. striata (1, 24, 31, 44); L. thunbergii (28); L. tomentosa (44); L. sp. (1, 5, 35, 38).
Uromyces lilii (Link) Fuck.: Fritillaria sp. (1).
Uromyces limonii (DC.) Lév.: Statice aurea (15); S. bicolor (1); S. japonica (1).
Uromyces linearis Berk. & Br.: Panicum repens (1, 40).
Uromyces macintirianus Barcl.: Hemigraphis sp. (31).
Uromyces mercurialis P. Henn.: Mercurialis leiocarpa (25).
Uromyces minor Schroet.: Trifolium lupinaster (14).
Uromyces oblongisporus Ellis & Ev.: Artemisia sp. (1). If the identification is correct this represents the second known collection of the species.
Uromyces orobi (Pers.) Lév.: Vicia unijuga (1).
Uromyces perigynius Halst.: Carex sp. (1).
Uromyces phaseoli (Rebent.) Wint.: Azukia subtrilobata (1); A. typica (1); Phaseolus angularis (5); P. aureus (1, 14, 22, 44); P. chrysantha (5); P. coccineus (1); P. mungo (1, 38, 44); P. radiatus (17); P. vulgaris (1, 5, 14, 17, 22, 31, 35, 38, 40); Vicia sp. (5); Vigna sinensis (31, 44).
Uromyces pisi (Pers.) Schroet.: Euphorbia sp. (26); Pisum sativum (1, 22).
Uromyces polygoni (Pers.) Fuck.: Polygonum aviculare (1, 14, 22, 25, 31, 35, 38, 44); P. multiflorum (44); Rumex sp. (1, 22).

Uromyces proeminens (DC.) Lév.: Euphorbia humifusa (1).
Uromyces punctatus Schroet.: Astragalus scaberrimus (1); A. sinicus (31); Oxytropis herta (28).
Uromyces pyriformis Cooke: Acorus calamus (1, 44).
Uromyces rugulosus Pat.: Campylotropis balfouriana (31); C. hirtella (31); C. polyantha (31); Lespedeza yunnanensis (1); L. sp. (35, 38).
Uromyces rumicis (Schum.) Wint.: Rumex sp. (1, 35, 38).
Uromyces saururi P. Henn.: Saururus chinensis (35, 38).
Uromyces setariae-italicae (Diet.) Yosh.: Setaria glauca (1, 22); S. italica (1, 14, 17, 23, 44); S. lutescens (16, 22); S. viridis (1, 15).
Uromyces silenes Fuck., see Uromyces inaequialtus.
Uromyces sojae Syd., see Phakopsora pachyrhizae. While Uromyces sojae is synonymous with U. mucunae Rabenh., the Chinese record on Glycine doubtless should be referred to Phakopsora pachyrhizae.
Uromyces solidaginis (Sommerf.) Niessl: Solidago virgaurea (1, 18).
Uromyces sophorae-flavescentis Kusano: Sophora flavescens (1, 14).
Uromyces sophorae-viciifoliae Tai: Sophora viciifolia (31).
Uromyces sophorae-japonicae Diet.: Sophora sp. (5).
Uromyces sphaerocarpus Syd.: Indigofera sp. (5).
Uromyces statice-sinensis Liou & Wang: Statice sinensis (1, 25, 44).
Uromyces striatus Schroet.: Medicago lupulina (1, 5); M. sativa (1, 14, 17, 34, 35, 38); Trifolium repens (31).
Uromyces striolatus Tranz.: Euphorbia sp. (28).
Uromyces tenuicutis McAlp.: Sporobolus indicus (22, 31).
Uromyces truncicola P. Henn. & Shirai: Sophora japonica (1, 22, 35, 38, 44).
Uromyces valerianae (Schum.) Fuck.: Valeriana dubia (1).
Uromyces veratri (DC.) Schroet.: Veratrum nigrum (1).
Uromyces viciae-craccae Const.: Vicia cracca (22).
Uromyces viciae-unijugae Ito, see Uromyces heimerlianus.
Uromyces vignae Barcl.: Vigna sinensis (1, 5, 14, 22, 31, 35, 38, 40); V. vexillata (5); V. sp. (5, 16).
Uromyces vignae-sinensis Miura: Vigna sinensis (1).
Uromyces sp.: Indigofera sp. (22).
UROPYXIS fraxini (Kom.) Magn.: Fraxinus chinensis (1, 18).
URTICA (Urticaceae) angustifolia: Puccinia fusispora.
Urtica dioica Thunb.: Puccinia caricis.
VALERIANA (Valerianaceae) dubia Bunge: Uromyces valerianae.
VERATRUM (Liliaceae) dolichopetalum Loesenes f.: Puccinia veratri.
Veratrum nigrum L.: Puccinia atropuncta; Uromyces veratri.
Veratrum taliense O. Loes.: Puccinia veratricola.
Veratrum sp.: Puccinia pachycephala.
VERNONIA (Compositae) patula Merr.: Phakopsora elephantopodis.
VICIA (Leguminosae) cracca L.: Uromyces fabae; Uromyces viciae-craccae.
Vicia faba L.: Uromyces fabae.
Vicia kulingana Bailey, V. sativa L.: Uromyces ervi; Uromyces fabae.
Vicia tetrasperma (L.) Moench.: Uromyces ervi; U. fabae.
Vicia unijuga A. Br.: Uromyces fabae; Uromyces heimerlianus; U. orobi.
Vicia sp.: Uromyces phaseoli; Uromyces fabae.
VIGNA (Leguminosae) sinensis (L.) Engl.: Phakopsora pachyrhizae; Uromyces phaseoli; Uromyces vignae; Uromyces vignae-sinensis.
Vigna vexillata Benth., V. sp.: Uromyces vignae.
VIOLA (Violaceae) acuminata Ledeb., V. betonicifolia Becker, V. canescens Wall., V. gryptoceras A. Gray: Puccinia violae.
Viola limprechtiana Becker: Coleosporium violae.
Viola mandshurica Becker, V. patrinii DC., V. prionantha Bunge: Puccinia violae.
Viola sp.: Puccinia violae; Uredo alpestris; Uredo iyoensis.
VITIS (Vitaceae) betulifolia Diels & Gilg, V. pentagona Diels & Gilg, V. vinifera L.: Phakopsora ampelopsidis.
WAHLENBERGIA (Campanulaceae) marginata A. DC.: Coleosporium campanulae.
WALDSTEINIA (Rosaceae) sibirica Trautv.: Puccinia waldsteiniae.
WIKSTROEMIA (Thymelaeaceae) indica Meyer, W. sp.: Melampsora yoshinagai.
WRIGHTIA (Apocynaceae) pubescens R. Br.: Hemileia wrightii.

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SUPPLEMENT 197

THE PLANT DISEASE WARNING SERVICE IN 1950

Supplement 197 November 15, 1950

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DIVISION OF MYCOLOGY AND DISEASE SURVEY

Plant Industry Station　　　　Beltsville, Maryland

THE PLANT DISEASE WARNING SERVICE IN 1950

Paul R. Miller and Muriel O'Brien

Plant Disease Reporter
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INTRODUCTION

In 1950 the diseases under consideration in the Crop Plant Disease Forecasting Program, namely, late blight of potato and tomato (Phytophthora infestans (Mont.) de Bary), tobacco blue mold (Peronospora tabacina Adam), and cucurbit downy mildew (Pseudoperonospora cubensis (Berk. & Curt.) Rostow.) were quite prevalent and in many cases very destructive. Several factors combined to encourage their destructiveness, a major one being the extremely favorable weather conditions of a cool-wet summer, ranging from six weeks to three months, over most of the plant-growing area.

As one result of this extremely favorable weather, late blight on tomatoes attained the most widespread distribution ever recorded in this country, with severity and loss equalling or possibly exceeding that suffered from the destructive 1946 outbreak. The disease moved westward, appearing in States where it had never been reported previously. It was widely reported in commercial acreages. In many cases untreated fields were completely destroyed. Infection of southern-grown transplants was again a contributing factor in occurrence and severity, according to reports from several areas, especially Mississippi, Illinois, Virginia, New Jersey, and Pennsylvania.

Regarding blue mold of tobacco, following the high January temperatures which were as much as 12 degrees above normal, this disease could have become very active. Extensive destruction was prevented by the warm-dry weather of February in the southern Atlantic States, the mildness of attack in other cases, and the thoroughness and effectiveness of control measures employed by growers.

Cucurbit downy mildew was more active on the watermelon crop this year than heretofore. This differential rate of development of downy mildew on watermelons and cantaloupes, which was noted by pathologists from several States, was probably due to the early and abundant build-up and distribution of inoculum especially virulent on watermelons.

PHYTOPHTHORA INFESTANS ON TOMATO:

Tomato late blight this year was of economic importance. It attacked sizeable acreages and affected the marketability of the crop. Estimated percent reduction in yield of late blight infected acreages, as shown in Table 1, varied from a trace to 95. Sources of infection included potato dump piles, volunteer potato plants, airborne spores, and southern-grown plants.

Noteworthy is the spread of late blight on tomatoes westward into Arkansas, Missouri, Iowa, and Nebraska (Figure 1).

Weather conditions this year were extremely favorable for the development of late blight (Figure 5). In the affected areas, mostly in the eastern to midwestern portions of the country, a warm winter, followed by a cool spring and warm-wet early summer with a cool-wet mid-summer, provided ideal conditions for the development of blight.

Fungicides used as sprays and dusts, as given in Table 2, included Dithane, Parzate, fixed coppers, Bordeaux mixture, nabam plus zinc sulfate, basic copper sulfate, zineb, tribasic copper, and ziram and copper. Control measures were effective when materials were properly applied under favorable spraying and dusting conditions. Table 2 lists materials used, formulae, results obtained, and the effectiveness of the control measures.

PHYTOPHTHORA INFESTANS ON POTATO:

Although not causing as much economic loss as on tomato, late blight on potato was prevalent this year in areas shown in Figure 2. It was distributed throughout the Atlantic Coast seaboard

States and in the Provinces of Ontario, Quebec, New Brunswick, and Nova Scotia, Canada. Sources of inoculum included diseased seed potatoes, cull piles, wind-blown spores from more southerly regions, and infected southern-grown tomato plants. Reports indicated that estimated reduction in yield, for the most part did not exceed 10 percent, except in Pennsylvania, where reduction in yield amounted to 100 percent in affected fields but averaged 9 percent for the State.

Ideal weather conditions for potato blight development occurred in most of the potato-producing regions during the past summer, i. e., cool-wet weather for extended periods of time.

Fungicides employed (Table 3), in the control of potato late blight included Dithane D-14, nabam, fixed coppers, Bordeaux mixture, zineb, basic copper sulfate, tribasic copper, and yellow copper oxide. In general, spraying and dusting of the fields together with local dry weather conditions, prevented local epidemics and kept the disease in check.

PERONOSPORA TABACINA ON TOBACCO:

The distribution of tobacco blue mold in 1950 is shown in Figure 3. Widespread severity was reported in certain localities, but the disease on the whole was relatively mild, despite its general distribution throughout the tobacco-growing areas.

Fungicides used (Table 4) indicated the preference for Fermate. Other fungicides employed were Dithane Z-78, Parzate, and zineb. There was no plant shortage and treatment for blue mold control was generally reported as very satisfactory this year. Reports have indicated a trend toward dusting rather than spraying for blue mold control, as dusts can be applied more rapidly and with less labor.

PSEUDOPERONOSPORA CUBENSIS ON CUCURBITS:

Cucurbit downy mildew occurred along the Atlantic Coast seaboard and in the southern part of Texas. Losses were reduced, since this disease appeared later than normal when the crop was mature or nearing maturity. (Figure 4).

Fungicides used in controlling cucurbit mildew, (Table 5) included nabam plus zinc sulfate, Copper A, fixed copper, Dithane D-14 and Z-78, Parzate, tribasic copper sulfate, zineb, and Bordeaux mixture. Reports indicated that P. cubensis can be controlled by a spray schedule. According to reports coppers were injurious and carbamates probably offer the best control fungicides.

Table 1. Estimated percent reduction in yield of late blight infected tomato acreages, 1950.

State or Province	Acreages infected with Late Blight	Percent estimated reduction in yield of infected acreage	Source of Inoculum
Ala.	5,000	80 (most fields 90 loss or greater)	Windblown spores
Ark.	8,500	25-90	Unknown
Conn.		25	Airborne spores
Fla. Dade Co.	13,000	Less than 1 percent in area as a whole, perhaps up to 10 in about 200 acres.	?
Ill.	4,500 (42 percent of total canning acreage)	15	Mostly from southern-grown plants.
Ind.	60,000	1 ton per acre	In doubt. First observations of disease were in fields set with southern plants and also in fields with no obvious source.

Table 1. (Continued)

State or Province	Acreages infected with Late Blight	Percent estimated reduction in yield of infected acreage	Source of Inoculum
Ky.		25	Probably blown in from South.
La.	Less than 100	50-75	Unknown. Fresh market tomatoes were heavily infected with late blight in late April and May.
Mich.	5,000	10-80 in individual fields	Unknown
Miss.	3,000	95	Plants from Florida
N.C.	4,000	50	Imported plants; potatoes.
N.Y.	15,000	Less than 1 percent	Local; no southern plants involved.
Ohio	20,000	10 of canning crop; 20 of rest.	Questionable. Some came into So. Ohio on plants. It is unlikely that was only source of inoculum.
Pa.	24,000	Average 8 for State. Maximum unsprayed - 50	Southern-grown tomato plants and potatoes
S.C.	5,000	2	Potatoes (?)
Tenn.	25,000	75	Local and airborne
Va. (Norfolk)	10,000 - 12,000	Less than 5.	Southern-grown tomato plants
(Blacksburg)		75	
W. Va.	3,000 - 5,000	35	Unknown
Wis.	1,200	50-70	Probably from potato dump piles and volunteer potato plants.
Canada Quebec		Trace to 30	
Nova Scotia	65	7 (?)	Windblown from potato fields.

Weather in 1950

The extensive activity this past year of all the diseases included on our program, and also the appearance of several others, has prompted us to present a brief analysis of the effect of the weather on the disease picture this year.

Figure 5 shows, for the entire country, the prevailing weather conditions during the months from January through September, 1950. At a glance one can see the similarity of weather conditions in January and February in the areas where downy mildew diseases occur. These conditions were warm-wet and warm-dry. The weather of March and April was completely opposite to that of January and February, cold-wet and cold-dry conditions obtaining in the eastern half of the country. May stands alone with principally warm-wet conditions in the eastern half of the country. In June heavy precipitation occurred along the coastal regions of Texas and Louisiana. Rainfall in showers and thunderstorms occurred from Illinois to West Virginia. Temperatures above normal and dry conditions prevailed in the Southeast and along the Atlantic Coast. The summer months of July, August, and September were characterized by cold-wet and cold-dry weather over most of the country. Generally speaking, therefore, the weather this year was extremely favorable for the incidence and development of mildew diseases.

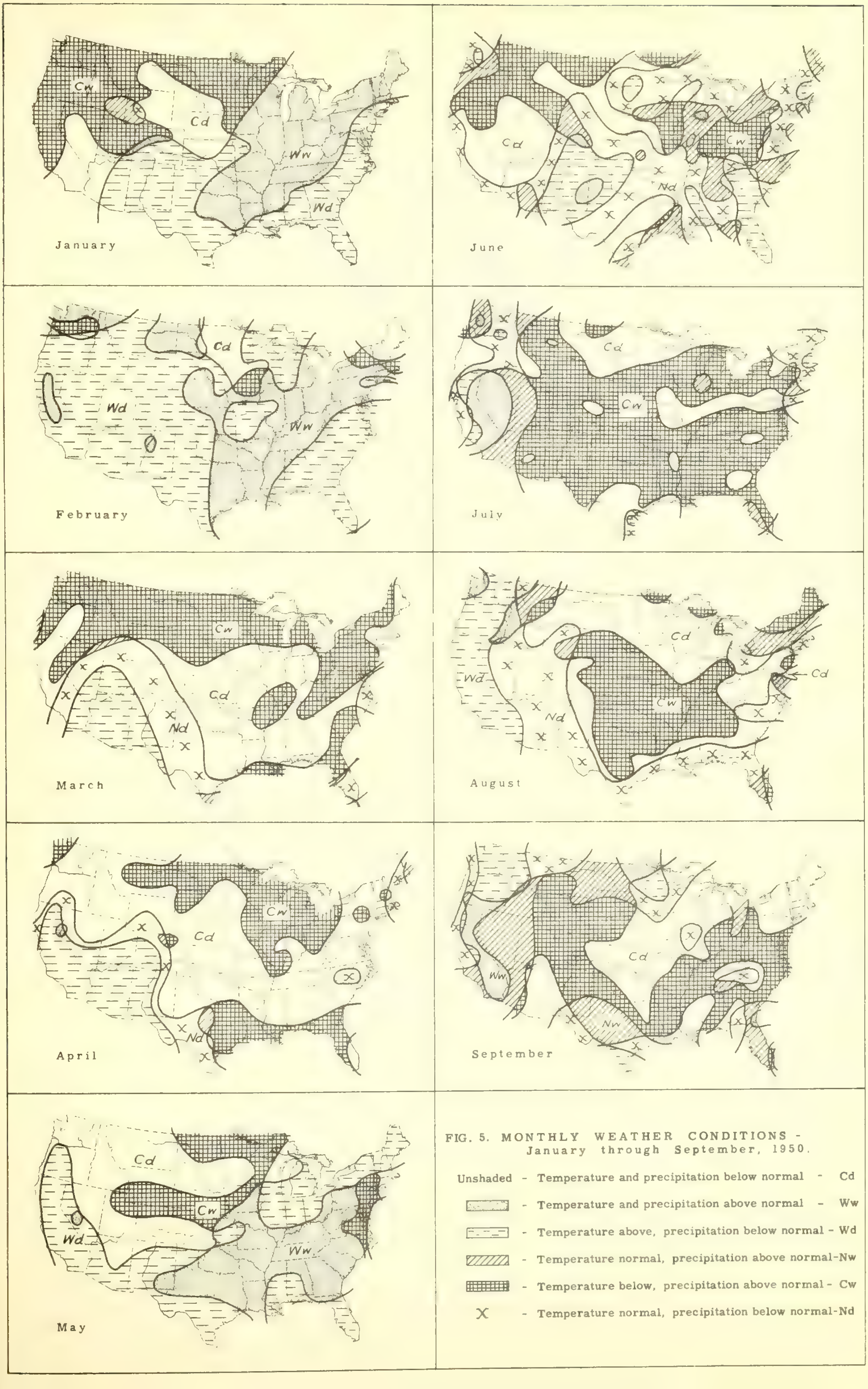

FIG. 5. MONTHLY WEATHER CONDITIONS - January through September, 1950.

Unshaded - Temperature and precipitation below normal - Cd

- Temperature and precipitation above normal - Ww

- Temperature above, precipitation below normal - Wd

- Temperature normal, precipitation above normal-Nw

- Temperature below, precipitation above normal - Cw

X - Temperature normal, precipitation below normal-Nd

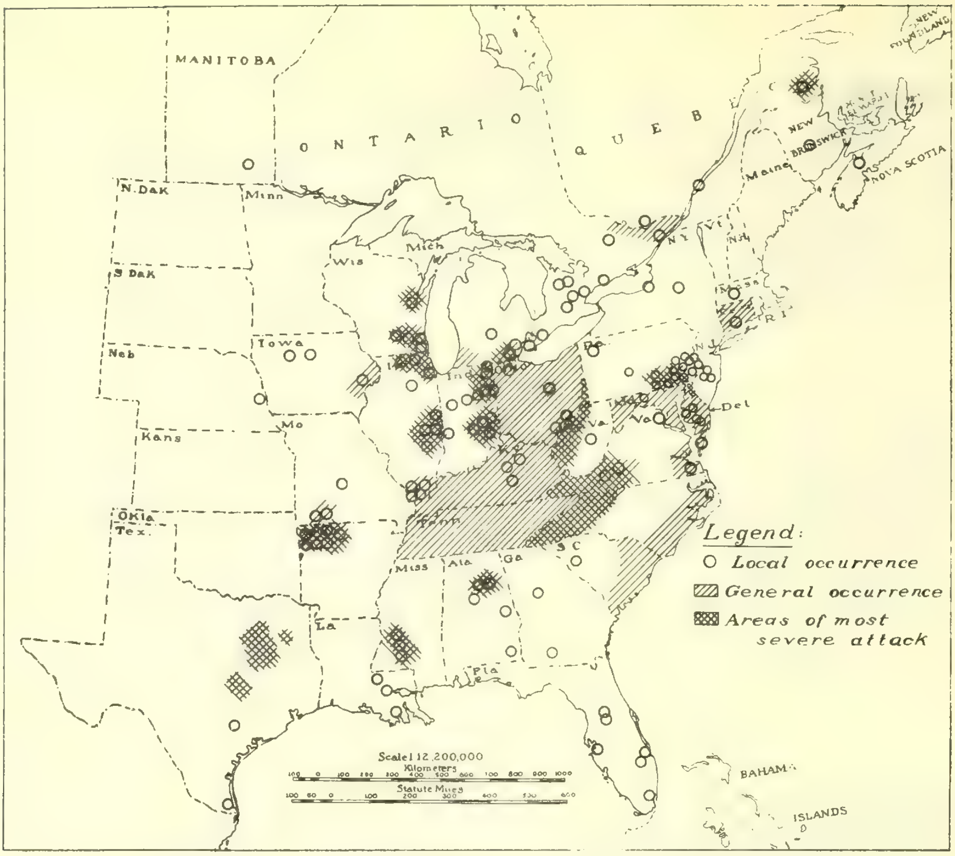

FIG. 1. DISTRIBUTION AND IMPORTANCE OF TOMATO LATE BLIGHT IN 1950.

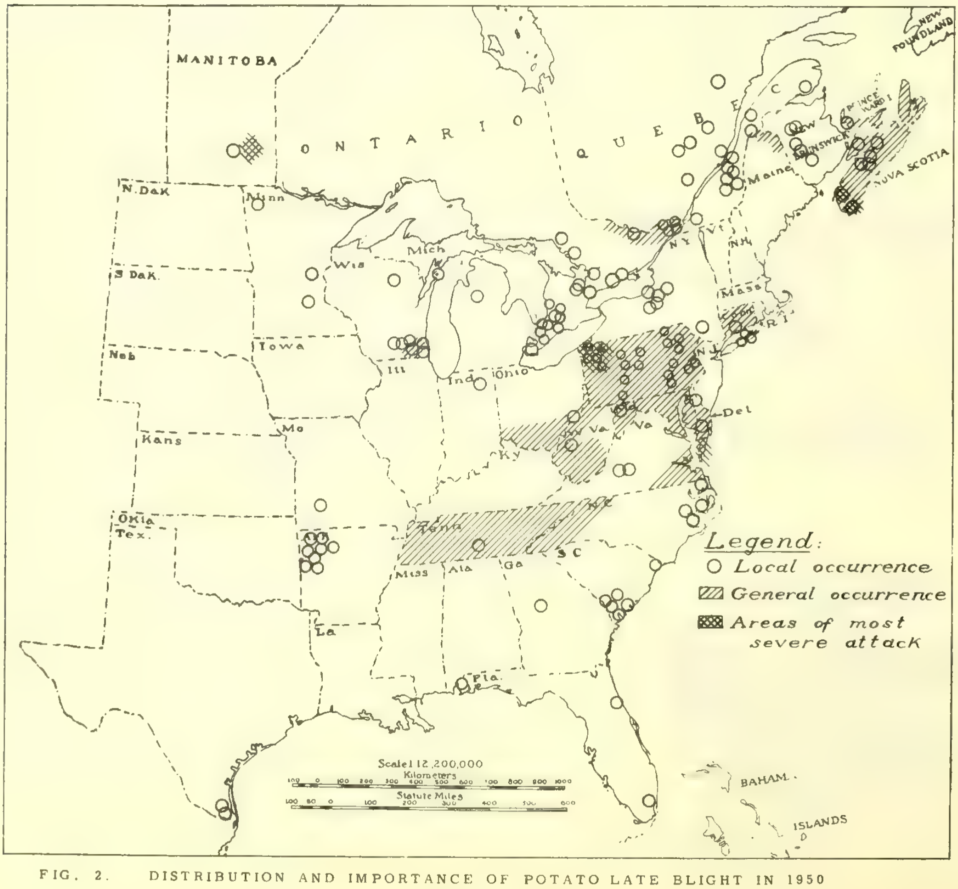

FIG. 2. DISTRIBUTION AND IMPORTANCE OF POTATO LATE BLIGHT IN 1950

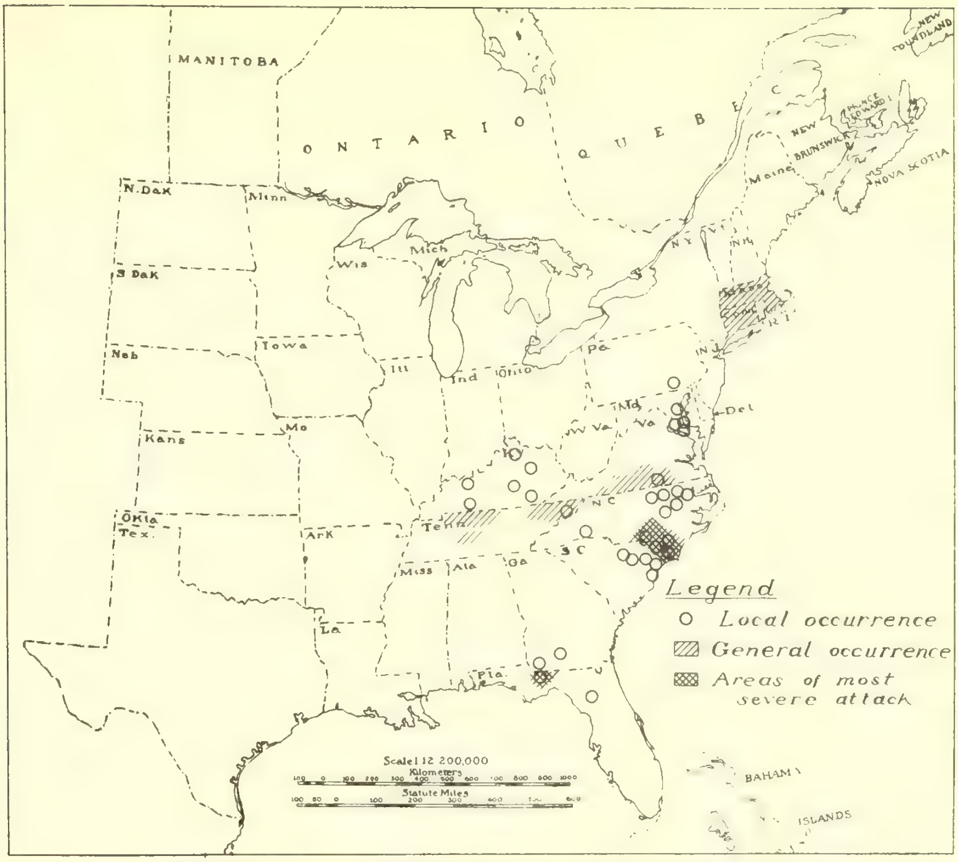

FIG. 3. DISTRIBUTION AND IMPORTANCE OF TOBACCO BLUE MOLD IN 1950.

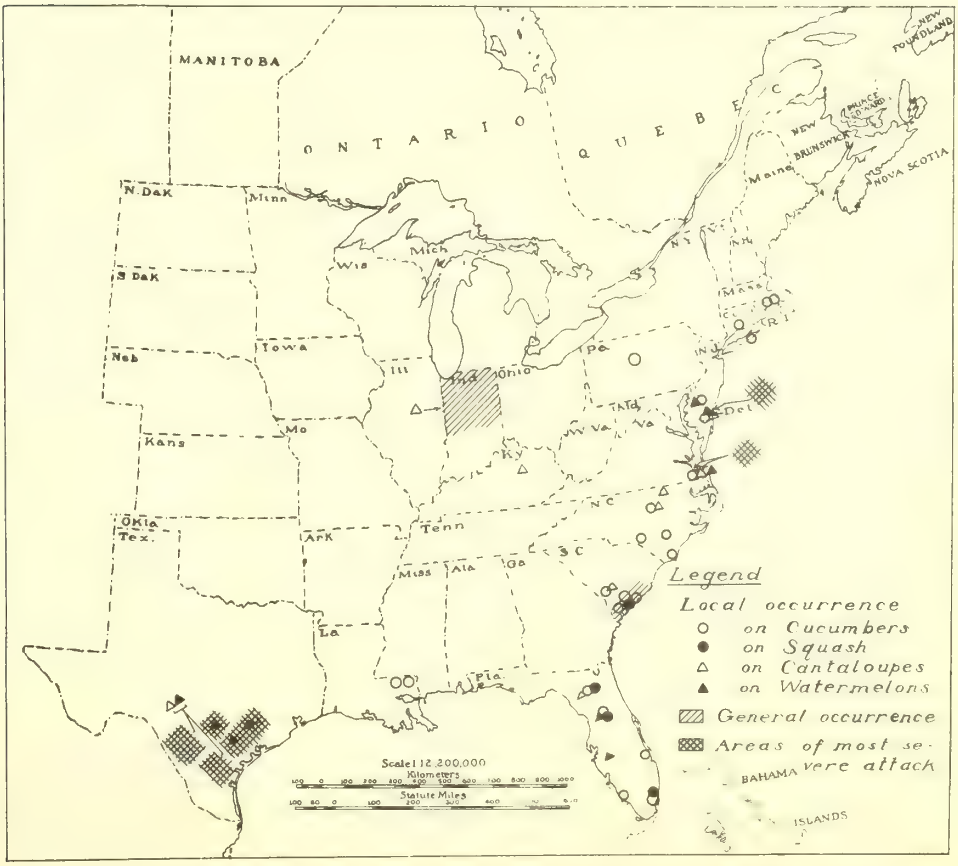

FIG. 4. DISTRIBUTION AND IMPORTANCE OF CUCURBIT DOWNY MILDEW IN 1950

Table 2 CONTROL OF LATE BLIGHT ON TOMATO· Materials used as Sprays and Dusts and their effectiveness, 1950.

State or Province	Materials	Formula or Dosage	Percent growers using	Results	Remarks
SPRAYS:					
Ala.	Liquid Parzate	2 qt. per 100 gal. plus 1 lb. $ZnSO_4$	20	Good	About half of the farmers in Etowah and Blount Counties of the North Alabama greenwrap area began a disease control program on fall tomatoes. After a couple of weeks of very rainy weather during early August, all but 7 or 8 farmers had abandoned the program due to severe blight damage. These farmers had not been able for various reasons, including the weather, to put the fungicides on as often as needed.
Conn.	Dithane	2-100	4.5	Fair	
	Fixed coppers	4-100	65	Good	
	Bordeaux	8-4-100	25	Good	
Fla. (Homestead)	Nabam plus zinc sulfate	2 qt., 1 lb./100 gal. (probably one-half of the growers used one-half lb. lime with the above formula)	100	Excellent (fair in 3 or 4 fields where application or schedule was inadequate)	Many growers use a fixed copper as a seedbed spray before late blight is reported in the area. To my knowledge, no one used copper sprays last year with the idea of controlling late blight, the seedbed use being nutritional as much as protective. One grower used Phygon XL (3/4 lb./100 gal.) experimentally; he reported good disease control, but his spray crew were irritated by the spray. Some airplane application of nabam and zinc sulfate did not afford the protection or control given by ground sprayers.
Ill.	Fixed coppers	2 lb. (Cu as metallic)/ 100 gal.	15	Good	Zerlate (1 appl.) used in alternating schedule prior to appearance of late blight; subsequent applications were Bordeaux or fixed copper. Fixed copper dusts appeared to hold blight in check, particularly in Vermilion (Ridgefarm) County.
	Bordeaux mixture	8-8-100	1	Good	
	Zerlate	2-100	5	See under "Remarks"	
Ind.	Basic copper sulfate	4-100	10	Good	Disease more widespread on tomatoes in Indiana than in any previous season of record. It was correlated with much above-normal humidities, consistently below-normal temperatures and above-normal rainfall, or very frequent rainfall.
	Zineb	2-100	1	Fair	
La.	Dithane D-14	2 qt./100 gal.	1		Small growers, who were affected with late blight in the spring, did not use sprays or dusts in general. Spraying and dusting is done by some of the larger growers in Plaquemines Parish, where late blight was not reported.
	Bordeaux Mixture	2-2-50	3		
	Fixed coppers		15		
Mich.	Bordeaux	2 applications	E	Excellent (applications made after blight started)	Late blight started early in August and weather conditions were favorable for blight. Untreated fields sustained heavy losses. However, sprayed fields came through with 15 to 18 tons per acre.
	Dithane	5 applications		good	
	Insoluble coppers	4 applications		Good	
Miss.	Copper A	4-100	?		Control measures started too late -- ergo, ineffective. We had an unusually windy spring this year, and I believe that contributed more than anything else to the total loss. Temperature and rainfall about same as past 2-3 years. In past 3 years local damage severe, but fungus was not so widespread as this year.
	Parzate	2-100	?		
	Dithane Z-78	2-100	?		
N. Y.	Ziram & copper	Ziram (2 lb./100 gal.) 8-4-100 Bordeaux	85+	Excellent	Most, if not all, growers used the split schedule of ziram and copper, usually in order of Z-Z-C-Z-C. In some areas, more copper was applied because of a late blight threat. In these areas tomatoes suffered more from anthracnose. In some non-sprayed (very few) fields, tomatoes were a complete loss from late blight.
N. C.	Bordeaux	4-4-50	0.1	Good - (Injury)	Acreages largely made up of home gardens and small market-gardening plantings. No serious damage to early green-wrap crop in eastern North Carolina.
	Fixed coppers	4-100	1.0	Good	
N. Dak.	Zerlate		10		
	Dithane Z-78		0		
	Cop-O-Zinc		0		
	Cuprocide		0		
	Phygon		0		
	Basic copper		50		
Ohio	Bordeaux	8-6-100	10	Excellent	Occurrence of severe losses was spotty. Areas no more than 25 miles apart varied widely in percentage of acreage affected and in percentage of fruits attacked.
	Fixed coppers	4-100	30	Excellent to good	
	Zineb (S)	4-1-100 liq. 2-100 dry	10	Good to fair	
Pa.	Dithane-Parzate etc.	2 qt.	5	Good	Conditions were quite good for late blight in western Pennsylvania during the late season, whereas the spread in southeast was early.
	Zerlate & fixed copper	1 and 2 lb. cop	25	Fairly good	
	Zerlate early, copper late	2 lb. Z and 4 lb. cop	40	Fair	
	Fixed copper	4 lb./100 gal.	20	Good	
S. C.	Dithane D-14	2-1-100	5	Excellent	Late blight appeared but was held in check by dry hot weather. Tomato prices good. No appreciable losses even in unprotected tomatoes.
Tenn.	Bordeaux	4-4-50	2	Excellent	Where numerous applications of fungicide made, good results reported.
	Fixed copper	2 lb. 50% powder	5	Poor	

Table 2. (Continued)

State or Province	Materials	Formula or Dosage	Percent growers using	Results	Remarks
SPRAYS: (Cont.)					
Va. (Blacksburg)	Insoluble copper	Various	15	Good	
	Zineb	Various	1	Good	
Va. (Norfolk)	Dithane Z-78	Manufacturer's recommendation	1	Good	Questionable results in control because, in fields where stem canker phase was present, dusts failed to check the disease. High temperatures during harvest season kept blight in check.
W. Va.	Bordeaux mixture	8-8-100	10	Good	The results with zineb this year were excellent. At the higher concentrations (3 pounds per 100) some yellowing of foliage was noted. It is not known whether the zineb was responsible directly or merely acted as a contributing factor.
	Tribasic copper (53%)	4 lb./100	5	Good	
	Zineb	2-3 lb./100	1	Excellent	
Wis.	Fixed coppers	Manufacturer's recommendation	35	Poor, as no fungicide used until blight appeared and in most cases only one or two applications put on.	Late blight really hit our main tomato canning area (Racine - Kenosha) hard. Weather conditions were ideal a good part of the time. Part of the acreage was airplane dusted and part was ground sprayed using side boom sprayer.
	Bordeaux	Not known	Very few		
	Carbamates	Manufacturer's recommendation			
Canada (Nova Scotia)	Bordeaux	4-3-40	50	Excellent	Commercial growers did an excellent job of holding blight in check. Most household gardens were destroyed by the middle of September.
	Zerlate + Bordeaux	2-100 gal. Z + 4-3-40	50	Excellent	
DUSTS:					
Ala.	6% zineb	25 lb./acre	20		See Alabama control in Spray schedule
	6% copper	25 lb./acre	10		
Ark.	Tribasic copper sulfate	7% dust	Very few	Good	
Conn.	Dithane		.5	Fair	
	Fixed coppers		5	Good	
Ind.	Basic copper sulfate	7%	5	Poor	
Ill.	Fixed coppers	7%	5	Good	
La.	Dithane	6% Dithane Z-78	2		
	Copper		1		
Miss.	Copper A	12%	?		
	Parzate	12%	?		
	Dithane Z-78	12%	?		
N. Y.	Ziram & fixed copper	10% ziram 7% metallic Cu	2	No late blight, but poor control of early blight.	
N. C.	Copper-lime	20-80	0.1	Good (Injury)	
	Fixed coppers	7% Cu	10	Good	
Ohio	Fixed coppers	14-86	30	Fair to poor	
Pa.	Fixed copper	7%	10	Fairly good	
S. C.	Tribasic copper sulfate	6-7% metallic Cu	35	Excellent	
	Dithane Z-78	6%	10	Excellent	
Tenn.	Zineb	1 1/2 lb. tech./100 gal.	1	Poor	
	Fixed copper	7%	5	Poor	
Va. (Blacksburg)	Insoluble copper	Various	15	Fair	
	Zineb	Various	1		
Va. (Norfolk)	Fixed coppers	7%	10	Questionable	Where stem canker phase present, dusts failed to check the disease.
	Dithane Z-78	Manufacturer's recommendation	10	Questionable	
	Parzate	Manufacturer's recommendation	5	Questionable	
W. Va.	Yellow copper oxide	5% metallic Cu	10	Poor	
	Tribasic copper	7% metallic Cu	15	Good	
	Zineb	10%	3	Excellent	
	Copper-lime	20-80	8	Good	
Wis.	Fixed coppers	Manufacturer's recommendation	25	Where weekly applications were kept up had fair control.	See Wisconsin control in Spray schedule
	Carbamates	Manufacturer's recommendation	Very few		

Table 3. CONTROL OF LATE BLIGHT ON POTATO: Materials used as Sprays and Dusts and their effectiveness, 1950.

State or Province	Materials	Formula or Dosage	Percent growers using	Results	Remarks
SPRAYS:					
Ala.	Dithane D-14	2 qt./100 gal.	10	Excellent	Late blight damaged 200 to 300 acres of potatoes in Alabama where no disease control was practiced. Most growers dusted or sprayed and this, together with fair weather, prevented an epidemic.
Fla. (Dade Co.)	Nabam plus $ZnSO_4$	2 qt., 1 lb./100 gal.	100	Excellent	Late blight in County during last two-thirds of crop growth but effective spraying kept it from potatoes. One grower tried airplane application of nabam spray on 40 acres. He reported late blight in this acreage but none in an adjacent 40 acres sprayed with a ground machine.
Fla. (Hastings)	Nabam	2 qt. nabam, 1 lb. zinc sulfate/100 gal.	80	Excellent	Late blight was mild as compared with an average year.
Ind.	Zineb	2-100	80	Good	Disease severe only where limited number, 5-10, sprays applied or where poor drainage resulted in prolonged wet soil. Considerable tuber blight in late potatoes in home gardens on mineral soil.
	Basic copper sulfate	4-100	10	Good	
La.	Dithane D-14	2 qt./100 gal.	10% of acreage		Although late blight was not reported from the spring crop of potatoes, the sprayed and dusted fields in general appeared to be in better condition than the untreated fields. This was due largely to insect control with insecticides used in conjunction with the fungicides and, perhaps, to some measure of early blight control.
	Fixed coppers		5% of acreage		
	Bordeaux mixture	4-4-50	5% of acreage		
Minn.	Parzate and Dithane		10±	Good	Surveys covered Northern Minnesota, Hollandale, and Twin City areas.
	Fixed coppers		10±		
N. C.	Bordeaux mixture	8-6-100	10	Good	Estimates only. A good crop of potatoes was produced in the early and late sections, but blight did reduce yields in local areas.
Ohio	Bordeaux	8-8-100	10	Excellent to good. (Many growers used Bordeaux in last spray only)	Late blight tuber rot quite general in late crop; seldom over 5%. Little evidence of disease was present in many fields as infection occurred very late (after mid-Stepember).
	Fixed coppers	4-100	5	Good to fair	
	Zineb (s)	4-1-100 liquid 2-100 dry	80	Excellent to good	
Pa.	Dithane or Parzate	2 qt./100 gal.	10	Fair	DDT used in most sprays and dusts. Liquid Parzate and Dithane, 2 lb. plus 1 lb. zinc sulfate. Blight got out of hand for many large growers using organics and also in some cases where copper sprays were used. Spray rings had more trouble than usual in keeping blight in check in areas northwest of State College. Growers using organics allowed blight to get a head start before switching to copper, with disastrous results in a number of cases.
	Dithane or Parzate early, Fixed copper, etc., late		50	Fairly good	
	Fixed copper	4 lb./100	25	Fairly good	
	Bordeaux	8-4-100	15	Good	
S. C.	Dithane D-14	2-1-100	Trace	Excellent	Late blight appeared, but caused little or no damage Sebago grown almost exclusively except in Horry County. Sebago resistant (partially) and has never suffered severely from blight. All fungicides gave excellent blight control.
Tenn.	Bordeaux	4-4-50	5	Excellent	
	Fixed copper	2 lb. 50% powder	2	Good	
W. Va.	Bordeaux mixture	8-8-100	20	Good	
	Tribasic copper(53%)	4 lb./100	5	Good	
	Zineb	2-3 lb./100	.5	Excellent	
Wis.	Bordeaux	8-8-100 at start; 8, 10-5-100 at finish	1 to 2	Good in north; apparently about same as carbamates in Kenosha area.	In some areas not enough applications were used during the season to give the fungicide a fair trial. It appeared that the carbamates gave better control in the Kenosha area than the copper materials. This was not true in the northern growing areas.
	Fixed coppers	Manufacturer's recommendation	3 to 5	Poor to fairly good	
	Carbamates	Manufacturer's recommendation	60	Poor to good	
Canada (New Brunswick)	Fixed copper and Bordeaux	Bordeaux 4-2-40 Imperial gallons. Fixed copper manufacturer's directions.		Good control	
(Nova Scotia)	Fixed coppers (early	4 to 7 lbs	60	Poor	Blight has destroyed from 50-100% of crop in Yarmouth and Dibgy Counties. Ten to 25% loss where some spraying was carried out. Many growers used fixed coppers early in season and switched to Bordeaux when the blight began to creep in. All growers switched in early September to Bordeaux.
	Bordeaux (seed potatoes)	4-2-40	100	Good	
(Prince Edward Island)	Bordeaux	10-5-100		Control depended on number of applications and timeliness of same.	Severe epiphytotic: Two heavy rains late in August washed spores into soil, resulting in tuber infections. Chemical vine killing was widely used.
	Basi-Cop	4 to 5-100			
	C.O.C.S.	4 to 5-100			
	Dithane D-14	2 qt.-100			
Quebec	Bordeaux mixture			Materials used gave a fairly good protection to the foliage.	
	Coppers with DDT				

Table 3. (Continued)

State or Province	Materials	Formula or Dosage	Percent growers using	Results	Remarks
DUSTS					
Ala	Zineb	6%	40	Excellent	
	Copper	5%	30	Good	
Fla. (Hastings)	Tribasic copper	6 to 10 % metallic	20	Good	
La	Dithane	6% Dithane Z-78	3% of acreage		
	Copper dusts		5% of acreage		
Minn.	Parzate and Dithane		70+	Good when correctly used.	
	Fixed coppers		70±		
N. C.	Fixed copper dusts	7%	60	Good to poor	
Ohio	Fixed coppers		2	Fair	
Pa.	Fixed coppers	7% & DDT	5	Fair	
S. C.	Tribasic copper sulfate	8-7% copper	60	Excellent	
	Dithane Z-78	6% Dithane	10	Excellent	
Tenn.	Fixed coppers	7%	1	Good	
Va. (Norfolk)	Fixed coppers	7%	15	Questionable	Questionable results because of local showers in the Cape Charles area.
	Dithane Z-78	Manufacturer's recommendation	15	Questionable	
	Parzate	Manufacturer's recommendation	5	Questionable	
W. Va.	Yellow copper oxide	5% metallic Cu	15	Poor	
	Tribasic copper sulfate	7% metallic Cu	10	Good	
	Zineb	10%	1	Excellent	
	Copper-lime	20-80	5	Good	
Wis.	Fixed coppers	Manufacturer's recommendation	Very few	Poor in general	
	Carbamates	Manufacturer's recommendation	Very few	Not known	
Canada (New Brunswick)	Fixed copper	Manufacturer's directions		Good	
(Prince Edward Island)	Oxychlorides and tribasics	30 to 40 lb.			

Table 4. CONTROL OF TOBACCO BLUE MOLD: Materials used as Sprays and Dusts and their effectiveness, 1950.

State or Province	Materials	Formula or Dosage	Percent growers using	Results	Remarks
SPRAYS:					
Conn	Fermate	Start with 1 lb. to 50 gal. of water but increase later to 2 lb.	95	Results have been almost perfect where applied twice a week. Infection was light this year, however, even in unsprayed beds. A number of Shade growers sprayed the fields with either Fermate or Dithane during an unusual outbreak in July. Not much data on results because the trouble soon stopped anyway.	The Fermate method of control is now standard here and is quite satisfactory, so we are not doing any more experimenting. Dithane is just as good, but the growers are in the habit of using Fermate so why change?
Ky	Fermate		Very small	No need because of mild outbreak.	Blue mold was very mild this year because of very little carry-over from last year. It is gradually reducing in injury from year to year as it did between 1937 and 1944.
N. C	Fermate	4-100	22	Good	More beds were successfully treated for blue mold control in 1950 than in any previous season. There was no plant shortage due to blue mold. Injury from weed control chemicals, drought, low temperatures, and insects caused many plant bed failures in some sections. All fungicides gave satisfactory blue mold control when properly used. There seems to be a strong trend toward the use of dusts as compared with sprays.
	Dithane Z-78	3-100	1	Good	
	Parzate	3-100	few	Good	
Pa.	Copper & Fermate	8-4-100 2 lb.	85	Good	Downy mildew did not get started to any degree this year. Spray schedule calls for Bordeaux 8-4-100 early and Fermate at 3 lb. later. Fixed copper is an alternate for Bordeaux.
	Zerlate or Parzate		5	Fair	
S. C.	Fermate	4 lb./100	few	Good	* New experimental fungicide from Carbide & Carbon Chemical Corp.
	Parzate	3 lb./100	few	Good	
	Z-78	3 lb./100	few	Good	
	5379 (Carbide & Carbon) *	1 lb./100	none	Good	
	5400 (Cabride & Carbon) *	1 lb./100	none	Good	
Tenn. (Greenville)	Ferbam (Fermate)	2 lb. in 50 gal. of water	10	Good	Good control of disease was secured with both ferbam and zineb using above dosages regularly at this Station. The zineb dust treatment was preferred because it could be applied faster than the spray with less labor involved. Prepared fermate dusts were not generally available. Disease appeared first in East Tennessee this year; whereas last year many plant beds were destroyed in Coffee County, Middle Tennessee, several days before appearance was noted in East Tennessee.
(Knoxville)	Ferbam	3 lb. tech./100 gal.	10	Excellent	A few growers use P. D. B. with good effect.
	Zineb	3 lb. tech./100 gal.	1		
Va	Ferbam	3 lb./100 gal.	80	Excellent	
DUSTS:					
Conn			Occasional grower	Results O.K.	
Fla.	Fermate	20%	50	Good	Dusts applied 3 times a week from 15 to 35 lb. per acre depending on size of plants. Dithane Z-78 and Parzate dusts have slightly better physical properties than Fermate dust. Some growers omitted (or discontinued) dusting because plants were growing too fast.
	Dithane Z-78	10%	20	Good	
	Parzate	10%	10	Good (some injury)	
N. C	Fermate	15%	32	Good	There seems to be a strong trend toward the use of dusts as compared with sprays.
	Dithane Z-78	10%	6	Good	
	Parzate	10%	1	Good	
S. C.	Fermate	15%	about 50	Good	
	Z-78	10%	few	Good	
	Parzate	10%	few	Good	
Tenn. (Greenville)	Zineb (Dithane)	5% dust	2	Good	
Tenn. (Knoxville)	Ferbam	10% dust	5	Good	Zineb dust treatment was preferred because it could be applied faster than the spray with less labor involved.
	Zineb	5% dust	1	Good	
Va	Ferbam	15%	10	Excellent	

Table 5. CONTROL OF CUCURBIT DOWNY MILDEW: Materials used as Sprays and Dusts and their effectiveness, 1950.

State or Province	Materials	Formula or Dosage	Percent growers using	Results	Remarks
SPRAYS:					
Fla. (Cucumbers)	Nabam + zinc sulfate	2 qt., 1 lb./100 gal.	100	Excellent where well applied.	Cucumber acreage is increasing. This is due to the fact that downy mildew can be controlled when a regular spray schedule using the dithiocarbamates is followed.
(Squash)	Nabam + $ZnSO_4$	2 qt., 1 lb./100 gal	5-10	Good	Summer squash usually is not sprayed for disease control in this area. A few growers did spray this year. Their stated opinion was that spraying was beneficial. Downy mildew is a "maturity" disease on squash and there is some question whether spraying is profitable.
(Watermelon)	Copper A	4 lb./100 gal.	20	Poor control	The use of copper as a watermelon fungicide is not encouraged. I look for more and more use of the carbamates because the coppers give injury.
	Dithane D-14	2 qt./100 gal.	30	Good control	
	Dithane Z-78	2 lb. plus zinc/100 gal.	10	Good control	
	Parzate	2 lb./100 gal.	20	Good control	
	Tribasic copper sulfate	8 lb./100 gal.	20	Good control	
Ind. (Muskmelon)	Zineb	2-100	0	Good (in experiments)	Early plantings from transplants in southern Indiana mostly escaped the disease but were badly injured by Alternaria. Complete defoliation of most late plantings in August throughout rest of State.
La. (Cucumber)	Bordeaux mixture	4-4-50	20	Good	Downy mildew light to moderate on 1950 fall cucumber crop. Very dry weather prevailing with no rain. Cucumbers irrigated.
N. Y.			Nearly 100% commercial, about 80% home gardeners.		Ziram, although used successfully against anthracnose and Cladosporium, has proved wholly worthless against downy mildew. The zineb types of spray or dust, when applied twice a week, gave excellent control and somewhat better yields than did copper. The commonly used fungicide was copper; Bordeaux mixture 8-4-100 for cucumbers and squash, and 6 to 7% low soluble copper dust on muskmelons, applied weekly.
Pa.	Fixed copper	4 lb.	40	Good	Downy mildew appeared in the State too late this year to cause much appreciable loss. The first observed was near State College on Sept. 2 and just getting started. Losses in western Pennsylvania, even where sprays were not continued, were negligible. Powdery mildew caused more damage to cucurbits in northwestern Pennsylvania where downy mildew failed to appear.
	Zerlate	2 lb	15	Fair	
	Dithane etc.	2-1-100	?		
S. C. (Cucumbers)	Dithane D-14	2-1-100	10	Excellent	Mildew appeared late in the spring and caused little damage. Price of cucumbers low and losses in dollars and cents negligible. Fall crop planted exclusively to mildew resistant varieties -- losses low except on a few farms where dusting poor. A hurricane during early September caused a considerable break in the fungicide schedule. The only growers who suffered severely from mildew (fall crop) had a 10-14 day interval between applications at this time Growers who sprayed or dusted properly at regular intervals had little or no disease. This was the first year that mildew was found on the resistant Palmetto variety except where this variety was planted adjacent to susceptible varieties. It appears that either we have a new race of the pathogen or just had better conditions for spread of the disease than in previous years.
	Dithane Z-78	2-100	trace	Excellent	
DUSTS:					
Fla. (Watermelon)	Copper-lime	20-80%	30	Poor control	
	Dithane	6.5% active ingredient	40	Good control	
	Parzate	6.5% active ingredient	10	Good control	
	Tribasic copper sulfate	8% copper	20	Good control	
La. (Cucumbers)	Fermate	8-10%	40	Good	
	Fixed coppers	7% metallic Cu	30	Good	
	Dithane Z-78	6-8%	5	Good	
	Other miscellaneous materials	---	5	Poor to good	
N. Y.			Nearly 100% commercial; about 80% home gardeners.		See N. Y. control under Spray schedule
N. C. (Cantaloupes and Cucumbers)	Tribasic copper	5% Cu	10	Good	The disease developed much more severely on cantaloupe than on cucumber in 1950.
	Zineb	6%	0.5	Fair	

Table 5 (Continued)

State or Province	Materials	Formula or Dosage	Percent growers using	Results		Remarks
DUSTS: (Cont.)						
Pa	Fixed copper	5%	30	Good		
	Dithane or Parzate	8%	20	Fair to good		
	Bordeaux	8-4-100	5	Good		
S. C. (Cantaloupe)	Dithane Z-78	6%	10	Good		Root knot and dry weather were unusually serious during the two-week period prior to harvest.
(Cucumber)	Dithane Z-78	6% Dithane	75	Excellent		See S. C. control under Spray Schedule.
	Zerlate	8% Zerlate	5	Excellent	Where properly applied	
	Tribasic copper sulfate	6% metallic Cu	5	Excellent		
(Watermelon)	Dithane Z-78	6%	30	Good		Mildew of little importance. Other diseases (Fusarium wilt, anthracnose, gummy stem blight) severe.

CONCLUSION:

In summarizing, it appears that during 1950 the mildew diseases were potentially serious because of the extended periods of favorable weather over most of the eastern United States. However, in spite of these conditions, losses were held to a minimum by the timely application of control measures. A large share for this success in controlling these diseases can be properly attributed to the very excellent and prompt reporting of the Key Pathologists who are the mainstay of the Plant Disease Warning Service.

DIVISION OF MYCOLOGY AND DISEASE SURVEY

THE PLANT DISEASE REPORTER

Issued By

THE PLANT DISEASE SURVEY

Division of Mycology and Disease Survey

BUREAU OF PLANT INDUSTRY, SOILS, AND AGRICULTURAL ENGINEERING

AGRICULTURAL RESEARCH ADMINISTRATION

UNITED STATES DEPARTMENT OF AGRICULTURE

SUPPLEMENT 198

INDEX TO SUPPLEMENTS 190-197, 1950

Supplement 198 Issued March 15, 1951

The Plant Disease Reporter is issued as a service to plant pathologists throughout the United States. It contains reports, summaries, observations, and comments submitted voluntarily by qualified observers. These reports often are in the form of suggestions, queries, and opinions, frequently purely tentative, offered for consideration or discussion rather than as matters of established fact. In accepting and publishing this material the Division of Mycology and Disease Survey serves merely as an informational clearing house. It does not assume responsibility for the subject matter.

PLANT DISEASE REPORTER SUPPLEMENT

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THE PLANT DISEASE SURVEY
DIVISION OF MYCOLOGY AND DISEASE SURVEY

Plant Industry Station Beltsville, Maryland

INDEX TO PLANT DISEASE REPORTER SUPPLEMENTS 190-197, 1950

Compiled by Nellie W. Nance

Plant Disease Reporter
Supplement 198

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LIST OF SUPPLEMENTS

Supplement 190. Plant disease forecasting: a symposium. pp. 1-33. January 30, 1950. The five invitational papers were presented at the American Association for the Advancement of Science Meetings, New York City. See its table of contents and author index below.

Supplement 191. Plant pathological investigations in the United States I. pp. 36-118. May 1, 1950. This supplement contains articles received by April 1. See its table of contents and author index below.

Supplement 192. Nation-wide results with fungicides in 1949, fifth annual report. pp. 120-187, May 15, 1950. Compiled by the Fungicide Committee of the American Phytopathological Society: Sub-Committee on Testing and Results of Newer Fungicides. See its table of contents and author index below.

Supplement 193. Plant disease losses: their appraisal and interpretation. pp. 190-362. June 15, 1950. See its table of contents. By K. Starr Chester.

Supplement 194. Some new or noteworthy plant disease records and outstanding developments in the United States in 1949. pp. 364-380. June 30, 1950. Compiled by Nellie W. Nance.

Supplement 195. Plant pathological investigation in the United States II. pp. 382-518. September 15, 1950. See its table of contents and author index below.

Supplement 196. An index of the plant rusts recorded for continental China and Manchuria. pp. 520-556. November 15, 1950. By George B. Cummins and Lee Ling.

Supplement 197. The plant disease warning service in 1950. pp. 559-572. November 15, 1950. By Paul R. Miller and Muriel O'Brien.

Supplement 198. Index to Supplements 190 to 197. pp. 575-588. (Issued March 15, 1951).

SUBJECT INDEX

ERRATA

CORRECTIONS FOR SUPPLEMENT 192
(From PDR 34(7):215)

NATION-WIDE RESULTS WITH FUNGICIDES IN 1949. FIFTH ANNUAL REPORT. CORRECTION: Our attention has been called to the omission of the active principle and source of M-294 used on muskmelons and reported on page 165 of Supplement 192. This material is cupric-N-nitrosophenylhydroxylamine, otherwise called copper cupferron, and was supplied by Sharples Chemicals, Incorporated, 317 Leconey Avenue, Palmyra , New Jersey. In the report submitted to us this material was also used as a spray against early blight on tomatoes with good results. Good results were obtained where 187 mgr. per square foot of the water-soluble ammonium salt as a soil treatment for damping-off in peppers was used. Greater concentrations inhibited growth. At the concentrations used in sprays this material was not toxic to muskmelons, tomatoes or string beans.

The results for downy mildew of onions reported on the bottom of page 163 should have been for Louisiana instead of Oregon. -- W. D. McClellan, Chairman, Sub-committee on Testing and Results of Newer Fungicides American Phytopathological Society.

(From PDR 34(12):415)

On page 167 of Supplement 192, "Nation-wide Results with Fungicides in 1949" it was reported that Robertson's Copper seemed to be ineffective against early and late blights of tomatoes and early blight of potatoes. It has been called to our attention that Robertson's Copper was as effective in controlling late blight of potatoes as the fixed coppers although both were less effective than the organic sulfurs. In limited tests Robertson's Copper looked promising for the control of early and late blight of tomato.

On page 178, paragraph 3, line 7, should read, "With both, the least effect ....." instead of maximum effect as given.

CORRECTIONS FOR SUPPLEMENT 193
(From PDR 34(8)240)

In Supplement 193, "Plant Disease Losses: Their Appraisal and Interpretation" by K. Starr Chester, please remember that Figure 7 on

page 236, Figure 17 on page 251, Figure 24 on page 311, and Figure 27 on page 321, have all been printed so that what should have been the top of the graph became the right-hand side. Thus, the lower edge for Figure 7 should be "Age of stand, years"; for Figure 17 "Age of basal wound (years)"; for Figure 24 the description of stages in development; for Figure 27 "Leafroll, %." -- Division of Mycology and Disease Survey.

CORRECTION FOR SUPPLEMENT 195
(From PDR 34(11):353)

In Supplement 195, on page 409, line 4, the variety name "Hales No.-45" should be changed to "Powdery Mildew Resistant Cantaloup No. 45". In line 9, "Powdery Mildew Cantaloup No. 6" should be changed to "Powdery Mildew Resistant Cantaloup No. 6".--S. P. Doolittle, Division of Fruit and Vegetable Crops and Diseases.